Communicating the Pixel: A Strategy for Guiding the Use of Remotely-Sensed Habitat Data in Coral Reef Management

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

Over the last decade, coral reef remote sensing research has focused on habitat map development. Advances in field methods, spatial and spectral resolution of remote sensing data, and algorithm development have led to more detailed map categories and to heightened map accuracy. Studies have provided guidance for practitioners in areas such as imagery selection, algorithm application, and class selection methods, but the product has remained relatively unchanged – a habitat map showing the spatial distribution of a range of substrate classes, classified primarily on the basis of their spectral signature. However, the application of such a product in a management context has not been elaborated by the remote sensing community.

The research described in this thesis addresses the challenge that the application of remotely-sensed coral reef information in a coral reef management environment elicits. In such an environment, the coral reef manager asks: "What can the map do to help me?", while the remote sensing scientist asks: "What type of information do you need?". The research described here aims to reconcile these two points of view, by answering the research question of this thesis:

How can coral reef remotely-sensed information address stakeholder-specific coral reef management objectives?

This question was answered through the development of a four-stage strategy. The strategy includes: 1) developing a traditional habitat map, 2) investigating stakeholder receptivity to the habitat map, 3) linking stakeholder interests with habitat data, and 4) illustrating the linked habitat data in what we term a management map. The strategy was applied on Bunaken Island, Indonesia, and involved the collection of both qualitative and quantitative data sets. The research was relevant to the communities on Bunaken Island, as they are directly responsible for the management of the coral reef resources surrounding Bunaken Island, and they are regularly planning and implementing coral reef management projects. The effectiveness of the four-stage strategy was evaluated in a framework that compares potential and actual uses of habitat maps and management maps in coral reef management projects. It was shown that management maps are superior to habitat maps for a wide range of management purposes.

This research has provided two main contributions to the field of coral reef remote sensing and management. The first is the four-stage strategy that results in the development of management maps, and the second is the framework for evaluating the effectiveness of the management maps.

This research seeks to traverse the gap between producers and users of coral reef remotely-sensed information. The recommendations made from this research addresses coral reef management procedures, action research, and cross-cultural communication. Each recommendation is founded on collaboration between scientist and manager. Such collaboration is crucial for successful application of remotely-sensed information to management.

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LIST OF ACRONYMS

Acronym	**Explanation**
BCCF	Bunaken Concerned Citizens Forum
BNP	Bunaken National Park
BNPMB	Bunaken National Park Management Board
CRMPA	Coral Reef Marine Protected Area
IUCN	International Union for Conservation of Nature
JICA	Japan International Cooperation Agency
MofT	Ministry of Tourism
MPA	Marine Protected Area
NGO	Non Government Organization
NOAA	National Oceanic and Atmospheric Association
NSWA	North Sulawesi Watersports Association
UNEP	United Nations Environment Program
UNSRAT	Universitas Sam Ratulangi
WCMC	World Conservation Monitoring Centre

GLOSSARY OF INDONESIAN TERMS

Indonesian Term	**Description**
Bahasa Bunaken	Local dialect on Bunaken Island in Northern Sulawesi
Bahasa Indonesia	National language of Indonesia
Bahasa Manado	Local dialect in Manado in Northern Sulawesi
Desa	Village
Desa Alung Banua	Alung Banua Village
Desa Bunaken	Bunaken Village
Desa Tanjung Parigi	Tanjung Parigi Village
Dok	Dock
Kapal Menggunakan	Passageway for boats
Laut	Ocean
Lebih Padang Lamun	Seagrass Increase
Legenda/Keterangan	Legend/List
Lereng Terumbu	Increase in coral
Lokasi Selam	Dive Location
Padang Lamun	Seagrass
Perubahan Dari 2001 ke 2004	Changes from 2001 to 2004
Peta Ikan Grouper Lokasi Pantau	Location of Grouper Fish Map
Peta ini mebuat Candace Newman	This map was created by Candace Newman.
Peta Kondisi Terumbu Karang	Coral Reef Condition Map
Peta Kondisi Terumbu Karang Dan Padang Lamun	Seagrass and Coral Reef Condition Map
Peta Perubahan	Seagrass Change Increase Map

Membaik Padang Lamun	
Peta Perubahan Membaik Terumbu Karang	Coral Reef Change Increase Map
Pulau Bunaken	Bunaken Island
Puncak Terumbu	Coral Increase
Sulawesi Utara	North Sulawesi
Taman Nasional Bunaken	Bunaken National Park
Utara	North
Zona Inti	Core Conservation Zone
Zona Pedukung Umum	Buffer Zone
Zona Pemanfaatan Masyarakat	Village use Zone
Zona Pemanfaatan Pariwisata	Tourism Use Zone
Zonasi	Zonation

CHAPTER ONE:
INTRODUCTION

1.1 REMOTELY-SENSED INFORMATION FOR CORAL REEF MANAGEMENT

The focus of this research is to develop a strategy that guides the use of remotely-sensed habitat data in coral reef management.

Within the field of coral reef remote sensing, researchers have for many years been developing coral reef habitat maps (Riegl and Purkis, 2005; Mumby *et al.*, 2004; Andrefouet *et al.*, 2003; Maeder *et al.*, 2002). Each map contains a collection of habitat types, which are defined by their combined structural framework and biological composition (Veron, 2000). These combined characteristics permit identification and delineation of the habitats within high-spatial satellite imagery (Mumby *et al.*, 2004; Holden, 1999; Knight *et al.*, 1997). Within the last decade, these habitat maps have in some places become the foundation of coral reef management plans, delineating the location of high coral cover to be protected, or the location of coral deterioration to be monitored (Bryant *et al.*, 1998). Some of the most exciting examples come from the United States, where habitat maps are being used to develop marine protected area boundaries and to recognize areas that are experiencing considerable coral reef decline (www.coralreef.noaa.gov). In Australia, habitat maps are at the foundation of the Great Barrier Reef Management Plan that identifies zones of commercial diving, fishing, and research (www.australiancoralreefsociety.org). These applications exemplify the ultimate purpose of these maps: to use the wealth of information contained in satellite imagery to provide an informational foundation from which coral reef management plans can be built.

The American and Australian successes have been made possible by the existence of both permanent funding for imagery and expertise in both remote sensing and management, along with a functional process for transforming the remote sensing imagery from raw data, not just into habitat maps, but further into a format useful for input to management. In other areas of the world, particularly in the many developing countries that house most of the world's coral reefs, this framework does not exist, and successful application of imagery to management is rare. Up-to-date high-resolution satellite imagery is expensive, which often limits the availability of imagery to research and government institutions partaking in donor-funded projects. This also means that expertise in the technical image processing often is limited to external researchers or consultants, trained in the production of habitat maps from satellite imagery. But transforming a high-resolution satellite image into a management-appropriate product requires considerable time and knowledge of the local environment and management issues, in addition to the technical expertise. The challenge, then, is to find a way to improve the information exchange between the remote sensing expert and the local user of the remotely-sensed information.

1.2 COMMUNICATING REMOTELY-SENSED HABITAT DATA

In response to the need for increased communication between technical expert and local stakeholder, a number of methodologies have been developed in other fields. Some of the more popular methodologies have used participatory processes for gathering and analyzing information – these include Participatory Rural Appraisal (PRA) and Participatory Learning and Action (PLA) (Chambers *et al.*, 1989; Davis-Case, 1990; Pretty *et al.*, 1995; Chambers, 1997; Abbot *et al.*, 1998). More recently new Information and Communication Technologies (ICT) are also being used to facilitate this information exchange (Richardson, 1997; McConnell, 1998; Moetsabi, 1998; Norrish, 1998).

In addition, participatory applications of Geographic Information Systems (GIS) have begun to emerge. This research field has built up quickly and is now referred to as Public Participation GIS (PPGIS), which involves local communities in the development of maps (Harris and Weiner, 1998; Jordon, 1998; Kyem, 1998; Alcorn, 2001; Harris and Weiner, 2002; Jordan, 2002; Kyem, 2002). Despite a growth in publications on this topic, however, there remain comparatively few instances of real examples of using PPGIS (Carver, 2001; Harris and Daniel, 2002). In addition, within the few existing examples the approaches, models, and products vary considerably and offer no commonly accepted operational strategy. Nevertheless, all PPGIS involve local stakeholders exchanging information with a GIS technician, who in turn provides guidance and expertise, with the goal of achieving an objective that necessitates the collaboration (Harris and Daniel, 2002). Our research applies this broad framework to the field of coral reef remote sensing.

The traditional remote sensing approach is driven by the scientist: traditionally, there are no requests made to stakeholder groups. A team of experts, mainly a team of coral reef remote sensing scientists, investigates a coral reef ecosystem and collects both structural and biophysical information at numerous spatial scales. During the field expedition, satellite or airborne multispectral or hyperspectral image data are collected. Next, the data are processed: atmospheric and water column corrections are applied, along with geometric registration. Field data are used to guide habitat selection and the resulting classification illustrates the 3-15 habitat types in a map (Green *et al.*, 2000). During the last decade, the field's research focus has been to develop habitat maps with increasing levels of accuracy. Because this research has been challenged by the presence of numerous immeasurable variables, and because it has been driven by researchers in academia rather than by management professionals, research has only slowly extended beyond development to application.

Until recently there has been little interest in remotely-sensed coral reef habitat maps within the field of community development in less-developed countries. Moreover, there have been few opportunities for local communities to use such maps mainly because these communities have been removed from decision-making processes related to coral reef management. In Indonesia, however, recent decentralization of the government has brought about increasing decision-making responsibilities at local levels, especially to small island communities (Nickerson and Olsen, 2003; Erdmann *et al.*, 2004). In the northern regions of Sulawesi, small island communities now have considerable control and power over their marine resources; they are responsible for developing and sustaining coral reef management (Erdmann *et al.*, 2004). If remote sensing-based coral reef habitat maps are to contribute to the conservation management of this region's coral reefs, some of the world's richest in terms of biodiversity, it is necessary to develop a procedure for transforming satellite imagery into information that can guide management decisions by local people who are not familiar with this technology.

1.3 THE RESEARCH QUESTION

The primary goal of this research is to investigate the assumption that remote sensing-based coral reef habitat maps can contribute relevant information to coral reef management. In doing so the research will set out to answer the question:

How can coral reef remotely-sensed information address stakeholder-specific coral reef management objectives?

Wording the question in this way enables a study not only of whether information obtained from remotely-sensed data can or cannot be used to address specific management objectives, but also how this can be achieved. In the process of answering this research question, a strategy was developed and a framework for evaluating the impact of the strategy on stakeholder groups was developed and applied.

1.4 A NEW APPROACH

The research reported in this thesis has resulted in the development of a four-stage strategy. The strategy begins with the development of a habitat map using the traditional remote sensing process. This is followed by three further stages that involve gathering, integrating, and illustrating stakeholder feedback. The focus is on enabling stakeholders to identify what habitats are most relevant to current management projects, and to identify how they want the habitat data presented. The approach is based on a participatory process to ensure that both direct and indirect stakeholder groups are involved in the process, and that stakeholders regularly provide feedback.

The research focused on the coral reef management plans for Bunaken Island, situated in Bunaken National Park, Indonesia's first national marine protected area. The predominant users of the coral reef resources are fishers and dive operators. They are involved, along with members of NGOs, the government, and the local university, in the development of management projects for the island. Within the last decade, management projects have included development of a management board and implementation of a zonation plan. Recent projects have included changes to landing permits, development of scholarships for students, and expansion of docks.

The data collected for this research occurred during three separate field expeditions to Bunaken Island in 2001, 2002, and 2004.

1.5 THESIS STRUCTURE

In the following chapter, the research is placed in the context of the relevant literature. In Chapter Three, the research approach is described and includes a description of the research methods. This chapter also includes a brief summary of the research methods and data collection procedures used in each stage of the strategy. In Chapter Four, the research site is described, positioning Bunaken Island within the wider geography of North Sulawesi and Indonesia. Chapters Five through Eight represent each of the four stages in the strategy: development of a habitat map, stakeholder receptivity to the habitat map, linking stakeholder management interests with habitat classes from the habitat map, and illustrating the linked information. Each of these chapters is partly written as a self-contained manuscript to highlight the fact that each stage is, in itself, a separate study. In Chapter Nine, the habitat and management maps are evaluated. Finally, in Chapter Ten a summary about the four-stage process and the transformation of habitat maps to management maps is provided.

CHAPTER TWO:
BACKGROUND AND RESEARCH SIGNIFICANCE

The research outlined in this dissertation has connections to numerous fields in both the academic literature and in practical applications in developing countries. The academic literature changes rapidly and at the most recent International Coral Reef Symposium held in Fort Lauderdale (2008), it is clear that successful coral reef management is dependent upon the effective use of high-tech tools, such as remote sensing and GIS, to deliver relevant and appropriate products. The practical application, or use, of these tools is also advancing rapidly. There is an immediate need for products that address coral reef deterioration at both large and small scales. The information needs are great, and it is clear that coral reef remotely-sensed information can make relevant and immediate contributions to address concerns of reef loss and future predictions of reef deterioration.

In this chapter, the roles of and linkages between coral reefs, remote sensing, and communication between scientist and manager are explored. Advancements in remote-sensing technologies to map coral reef environments are described and the capabilities of the technology to address coral reef management information needs are illustrated. A review of communication between scientist and manager and the inherent challenges follows. In the last section of this chapter an science to management experience, in which the researcher was involved whereby coral reef information from SPOT imagery and coral health from video transects is communicated to residents of a Fijian community, is described. This chapter contains the following citation (see below), and has been reproduced with several changes, and with permissions from the authors.

Newman, C., LeDrew, E. and A. Lim. 2006. Mapping of Coral Reefs for Management of Marine Protected Areas in Developing Nations Using Remote Sensing. *In* LeDrew, E. and L. Richardson [eds.] Remote Sensing of Aquatic Coastal Processes. The Netherlands: Springer. 325 pp. 89 illus.

2.1 INTRODUCTION

Fifty years ago, the Australian High Commission laid down the challenge of developing a remote sensing integrated management plan to 'conserve and protect' the Great Barrier Reef. Thirty years later, over 100 marine protected areas, conserving and protecting Australia's reef heritage evolved, represent the combined efforts of hundreds of scientists and managers, and the appropriate integrated use of some of the most advanced satellite technology available. Today, that same challenge remains in other countries, especially developing countries.

Many remote sensing projects now aspire to the dual mission of identifying underwater features at higher spatial scales and integrating this identified information with local management strategies (Brando and Phinn, 2007). On the ground, this is a huge task, requiring extensive training, specialist knowledge, and large financial and time investments. Regardless of these efforts, environment representatives, activists, planners, and managers claim that the returns far outweigh the costs. This dual mission, however, has attracted a range of admirers and critics (ICRS members, July 2008, personal communication).

Several critics note that the lack of success of both developing remote sensing technologies to separate habitat features (Goodman and Ustin, 2007; Maeder *et al.*, 2002; Holden and LeDrew 2001), and interpreting mapped underwater features in a biologically and social-culturally significant manner, has led to questions concerning its usefulness (Brando and Phinn, 2007). Others have argued that the integration of remote sensing in management plans is conceptually possible, and may yield considerable benefits, if the ideal integration is found (Turner and Klaus, 2005).

2.2 EFFECTIVE MANAGEMENT AS A RESPONSE TO THE CORAL REEF 'CRISIS'

There is general agreement amongst scientists that the majority of reefs around the world are being negatively affected by human and natural events with increasing frequency and magnitude (Kleypas *et al.,* 2001). As a result, reefs are degrading at a rate faster than their rebounding and recruitment potential (Souter and Linden, 2000; Porter and Tougas, 2001). Reefs are at risk; this is no longer in question (Table 2.1). On June 26, 2004, scientists, managers, and government officials from around the world gathered for the 10th International Coral Reef Symposium, in

Okinawa, Japan, to discuss some of the greatest challenges facing reefs today, and the technologies that may help to provide answers. The theme, ‘stability and degradation of coral reef ecosystems’, echoed the real concerns facing coastal communities, from the well-developed tourist communities along the beaches of Hawaii to the small island fishers in the villages of Indonesia. Many guest speakers highlighted some of the most complex issues that, over the years, have deterred scientists from attaining a comprehensive understanding of coral reef ecosystems, and as a result, a manner in which to effectively stabilize or improve existing conditions.

One clear picture circulated throughout the conference: coral reef ecosystems are both locally and globally valuable but continue to face threats from coastal development, overexploitation, destructive fishing practices, and marine-based pollution. Several scientists have projected that, if impacts to coral reef ecosystems halted today, reefs would still require decades to return to a level of productive stability. A level where large predators, such as groupers, dolphins, and sharks dominate, and control lower levels of marine populations. Considering the rate at which coastal tropical environments are affected by human activities, and the presently known recovery rate of reef ecosystems to stresses, it appears as if there may not be enough time, information, and effort available to implement appropriate management strategies to preserve what remains of coral reef ecosystems (Hoegh-Guldberg, 1999; Risk, 1999).

Table 2.1. Location and status of reefs at risk.

Location	**Reef Status**
Caribbean and Atlantic Ocean	2/3rd of reefs are at risk and 1/3rd at high risk
Indian Ocean	> ½ of the region’s reefs are at risk
Middle East	2/3rd of the reefs are at risk in the Gulf
Southeast Asia	> ½ are at high risk and >2/3rd are at risk
Pacific	2/3rd are at low risk; 1/3rd are at no risk

Source: Bryant *et al.*, 1998.

Within the last decade there has been an obvious realization of the dangers human activity can cause to reef ecosystems (Birkeland, 2004). As a result, a concerted international effort to manage coral reef ecosystems in the most effective way possible has ensued. One management response to the reef ‘crisis’ has been to develop a completely comprehensive global view of reef health (Bryant *et al.*, 1998) for the purposes of: 1) illustrating areas where reefs are at risk; 2) establishing protected areas where human activity is not permitted; and 3) increasing awareness of human impact on coral reefs and their subsequent response to impacts. Government agencies, coral reef organizations, researchers, and scientists worldwide have been involved in developing strategies that address these issues in the most effective and appropriate manner possible (Hatcher, 1999). But, arguments over effectiveness have slowed responses and generated suspicions in appropriate protection and remediation strategies (Wells *et al.*, 2007). Fortunately, in more recent years there has been an explosion in the wealth of coral reef information, albeit scattered in databases all over the world (Green *et al.*, 1996) and this has renewed confidence in scientific abilities to devise strategies that can bring about management of human activity and changes in our attitudes towards coral reef ecosystems (www.gefcoral.org).

Today, a myriad of knowledge bases exist to assist scientists and managers in describing the condition of reefs within spatially isolated and dotted seascapes. These knowledge bases span from biological to socio-economic information, and over the years have become more focused, immense, and increasingly available to international researchers, managers, and planners (Wilkinson, 2000). In addition, these knowledge bases are evolving to serve the information needs of coastal managers. For coastal managers, decision-making is a function of timely, accurate, and relevant information. When available, they utilize gathered and analyzed scientific information to guide the development of management strategies through a complex seascape imbedded with social and biological elements. Information demands are immense, and growing, as management plans grow to encompass more components that resist static and predictable frameworks.

Over the last decade, remotely sensed technology has carved a place in this knowledge base. Moreover, this place continuously expands with the collection of more satellite imagery and data from field surveys. To the benefit of scientists and managers, this combined effort of image collection, with concurrent field validation, has boosted the precision and accuracy of remotely sensed information. With more recent remote sensing efforts, reef habitat types and their inhabitants have been detected at finer spatial scales, while changes in reef processes have been identified using more frequent repeat cycles. Improvements to sensor capabilities have broadened the prospect for remote sensing to provide more than traditional maps of habitat distribution, as important as they might be, and provide additional information that allows reef scientists and managers to establish baseline data from which comparisons can be made to assess the status of reefs, as well as the management strategies in place. With an increasing interest in devising monitoring strategies to evaluate management plans, remote sensing also provides input on a regular and timely basis. As a result, remote sensing is increasingly being relied upon to provide information that can complement and improve management strategies that seek to conserve coral reef resources (Klemas, 2001).

2.3 CORAL REEF MARINE PROTECTED AREAS AS A MANAGEMENT MODEL

Many organizations have evolved to tackle various aspects of coral reef management. These include monitoring programs at regional and global levels; construction of data bases of coral reefs and their resources; organizations that coordinate reef research and conservation strategies; and organizations that seek to raise public awareness of reefs. One common strategy is the creation of Coral Reef Marine Protected Areas (CRMPAs) for managing the impact of human activities on coral reefs, and the services that they provide. CRMPAs are seen as a key component of a much larger integrated system, and one that requires extensive monitoring to determine patterns and causality of change, factors that can initiate and confirm management interventions. Much of the stimulus for advocating CRMPAs is the recognition that coral reefs are a beacon for encroaching human and natural stressors on coastal environments, and subsequently coastal livelihoods.

Although CRMPA's are not all created with the same purpose in mind, each requires a set of physical and social information for design, maintenance, and long-term sustainability. In 2003, over 100 countries had some form of coral reef protected areas, each motivated by a different vision and each incorporating different biophysical elements (Gubbay 1995; Agardy 1997; Kelleher 1999). On the ground, these protected areas were designed for a number of different purposes: 1) limit human activities in deteriorating areas; 2) prohibit fishing in regions where large predators spawn; and 3) permit selective activities in areas where interests concern sustaining levels of existing biodiversity. More recently, to satisfy social, commercial, planning, and government interests, there is interest in monitoring CRMPAs and evaluating their effectiveness on ecosystem health.

2.3.1 Marine Protected Area Defined

Explicit calls for Marine Protected Areas (MPAs) were made during the 17th IUCN general assembly in 1988, the IVth World Parks Congress in 1992, the World Summit on Sustainable Development in 2002 and more recently at the Vth World Parks Congress held in Durban, South Africa in September of 2003 (IUCN, 2003). At each assembly the definition of an MPA was drawn from the International Union for Conservation of Nature and Natural Resources (IUCN), which describes an MPA as "…an area of intertidal or subtidal terrain, together with its overlying waters and associated flora and fauna, historical and cultural features, which have been reserved by legislation or other effective means to protect part or all of the enclosed environment" (Kelleher, 1999). Although this definition provides considerable room for interpretation, the IUCN focused the definition by establishing six categories of protected areas, which apply to both marine and terrestrial environments, and reflect the diversity of practical uses and ecological settings that MPAs include (Table 2.2). In essence, MPAs are tools through which marine areas can be managed.

Table 2.2. Categories of MPAs established by the IUCN.

Category	Description
I	Protected area managed mainly for science or wilderness protection (Strict nature reserve/Wilderness area).
II	Protected area managed mainly for ecosystem protection and recreation (National Park).
III	Protected area managed mainly for conservation of specific natural feature (National Monument).
IV	Protected area managed mainly for conservation through management intervention (Habitat/Species Management Area).
V	Protected area managed mainly for landscape/seascape conservation and recreation (Protected landscape/seascape).
VI	Protected area managed mainly for the sustainable use of natural ecosystems (Managed Resource Protected Area).

Source: Kelleher, 1999.

2.3.2 A Cornerstone of Marine Protected Areas

In the early stages of developing a CRMP managers, seek out information from databases for the design of maps containing spatially explicit information. Often the intent is to construct a map that combines locally significant regions with meaningful and categorized seascape features. Participatory mapping is a normal feature of CRMPAs in which stakeholders participate in defining and identifying significant areas, which in turn generates a greater awareness for the condition of these areas, and elicits a stronger sense of resource ownership. A second increasingly common feature of CRMPAs is the integration of information taken from images captured by sensors onboard satellites or aircrafts. With greater capabilities to extract biophysical information from images, including habitat identification, reef health assessment, and change, images are viewed as an ideal tool for illustrating and assessing large spatial areas, which would take weeks or months using traditional ground surveys.

A benefit of remote sensing that befits coral reef management strategies is that it can be used to describe multiple biophysical components within a coral reef system. Given the complexity of managing a multi-component system in which everything is connected to everything else, managers are faced with the challenge of bringing together those components that are appropriate and drive changes in the aquatic ecosystem. Based on the physical characteristics of these components, remote-sensing technologies can target and then illustrate them in a spatially and temporally explicit manner. A contribution of this magnitude, successfully identifying and assessing key drivers of change for CRMPAs, may be one of the most important steps in the quest to manage natural resources.

2.4 MAPPING CORAL REEF ENVIRONMENTS

The fundamental characteristics for mapping coral reef environments rest in both aerial photography and digital imaging methods. In both approaches, the process involves capturing reflected light energy. Processing, calibrating, correcting and analyzing the imagery produces a classified image that separates out features of interest, which are selected by the operator. For imagery of tropical islands, this often means identification of coral geomorphology, biology, and nearby ecosystem counterparts that reside within a depth to which light can penetrate. Certain types of imagery are more useful than others, depending on the eventual purpose of the imagery. In this section, the differences between aerial photography and satellite imagery are explored and the advancements of remote sensing technologies, since 1998, are examined. With every technological advance, there remain challenges, and these are described at the end of this section.

2.4.1 Aerial Photography versus Digital Imagery

Aerial photography lags behind digital imagery in several areas, especially with multi-variable image extraction capabilities, but it exhibits properties of comparatively lower cost and technology that are particularly attractive when mapping reef environments in developing countries (Table 2.3). Aerial photography has been successful in mapping structural loss (Lewis, 2002), reef areal extent (Thamrongnawasawat and Hopley, 1994), and benthic communities (Cuevas-Jimenez and Ardisson, 2002). It has also been used as a tool for proactive management (Riegl and Piller, 2000). Generally, an aerial photograph is considered successful at mapping when: 1) the spatial resolution of the map or image conforms to the complexity of the environment so that details of most interest are revealed; 2) the film is sensitive to wavebands that penetrate the overlying water and illuminate the architecturally complex bottom structure; and 3) the final product is reliable (Chauvaud *et al.*, 1998). With the overwhelming volume of archived available aerial photography, there is a trend towards integrating digitized aerial photographs with digital imagery to improve delineation of features and thus, image accuracy (Green *et al.*, 2000).

Table 2.3. Comparison of aerial photography and digital imagery of shallow coral reef areas.

Issues	Aerial Photography	Digital Imagery
Discrimination obstructed by overlaying water	Difficulty with discrimination due to wave action particularly from low level photographs	Difficulty with discrimination, but can apply radiative transfer correction
Tendency for confusion between bottom types	Improved bottom type discrimination with input from an informed operator	Improved bottom type discrimination with algorithms and *in situ* data
Geomorphological separability	Provides more accuracy for fine descriptive resolution	Provides detailed and broad zonal information
Wavelength data	These data are lost following digitizing	Wavelength data are retained and can be used to extrapolate biological or physical information
Cloud cover interference	Creates shadowing	Creates shadowing and disrupts wavelength signatures
3-D perspective	With relative ease a 3-dimensional portrait is formed following the overlay of stereo pairs	Can be achieved by overlaying imagery on a bathymetric image.

Continued from page 13.

Issues	Aerial Photography	Digital Imagery
Familiarity with the aquatic system	Need for remote sensing operator to be familiar with the spatial patterns with the aquatic system	Need for the remote sensing operator to be not only familiar with spatial patterns, but also biological processes that may be revealed within wavelength data
Standardization	Can be geometrically oriented, but contains distorted margins	Requires radiometric and geometric standardization prior to comparison of images through time
Availability and costs	High availability and costs when coverage is required for large areas	Requires scheduled satellite Overpass with minimum purchase order leading to high costs

Compiled from Chauvaud *et al.*, 1998, Mumby *et al.*, 1997, Sheppard *et al.*, 1995.

2.4.2 Past and Present Sensors

Over the past 20 years, sensors have evolved in their capability to capture spatial and temporal characteristics of coastal resources inhabited by coral reef ecosystems (Table 2.4). The evolutionary route of mapping coastal environments began with measurements of ocean temperatures, chlorophyll, and sediment concentrations (Robinson, 1985). Features that existed with a large spatial extent, which exhibited stable behaviour over time, and elicited a strong and distinct spectral response were readily observed using passive remote sensors (Robinson, 1985). These sensors offered the advantage of retrieving environmental information for a region within a short period of time that normally could only be examined on the ground within a timeframe of weeks or months. Areal coverage, timely data acquisition, digital representation of marine features, and temporal changes in environmental attributes are still prominent advantages to airborne or spaceborne imaging.

Table 2.4. Sensors with spatial resolutions greater than 10m.

Sensor	Satellite	Operation	Spatial Resolution	Spectral Resolution	Temporal Resolution	Further Information
Hyperion	EO-1	2001 – present	30 m (MS)	220 bands 0.4 to 2.5 μm	A target can be imaged 5 times during 16 days	http://eo1.gsfc.nasa.gov/Technology/Hyperion.html
ALI	EO-1	2000 – present	30 m (MS) 10 m (pan)	10 Bands	16 days	http://eo1.usgs.gov/ali.php
ETM +	Landsat 7	1999 – present	30 m (MS) 15 m (pan)	7 Bands 3 visible	16 days	http://geo.arc.nasa.gov/sge/landsat/daccess.html
OPS	JERS-1	1992 – present	18.3 m	8 Bands 2 visible	44 days	http://www.nasada.go.jp/index_e.html
LISS	IRS	1988 – present	23.5 – 73 m (MS)	LISS-I and II: 4 Bands 3 visible	22 – 24 days	http://www.spaceimage.com/
MESSR	MOS	1987 – present	50 m	4 Bands 2 visible	17 days	http://www.nasda.go.jp/index_e.html
TM	Landsat 5	1984 – present	30 m (MS)	7 Bands 3 Visible	16 days	http://landsat7.usgs.gov/index.php
MSS	Landsat 1 – 7	1972 – present	~ 80 m (MS)	7 Bands 2 visible	16 days	http://geo.arc.nasa.gov/sge/landsat/daccess.html

In recent years, there has been an explosion of interest in hyperspectral and high spatial resolution satellite imagery (Table 2.5) (Green *et al.*, 2000). The appeal is in the enormous versatility that accompanies these sensors as operators mix and match spatial and spectral resolutions (Klemas, 2001) to create an ideal suite of specifications for mapping reef features. The finer spatial and spectral detail is useful for improving discrimination between similar reef features, while the temporal flexibility allows the operator to avoid unfavorable environmental conditions (Green *et al.*, 1996). In 1999, the IKONOS satellite was launched and has since collected radiometric detail in 1-m panchromatic and 4-m multi-spectral detail. This increased spatial resolution has proven to be beneficial in classification of reef structure (Mumby *et al.*, 2004)

A disadvantage of some of these newer satellites with commercial mandates is a minimum coverage order requirement for non-US regions that is typically large and costly, thereby limiting its use to well-funded organizations (Green *et al.*, 2000). In addition, computer storage space and processing requirements increase exponentially with higher spatial and spectral resolution data (Aplin *et al.*, 1997). A further disadvantage to some airborne systems is that they are often restricted to their country of origin (Green *et al.*, 2000). Transporting sensors is difficult and even when a system is permitted to enter a country, necessary revisions to the host aircraft may not be permitted (M. Monaco (NOAA), Personal Communication, February 1999).

Table 2.5. Sensors with spatial resolution less than 10 m.

Sensor	Agency	# of Bands	Spatial Resolution	Spectral Range (nm)	Temporal Resolution	Further Information
AISA	Karelsilva Oy	286	.2 - 5 m	450 – 900 nm	Sensor	http://www.specim.fi/products-aisa.html
AVIRIS	NASA/JPL	224	< 10 m	400 – 2450 nm	Sensor	http://makalu.jpl.nasa.gov/html/overview.html
CASI 2	Itres Research Ltd.	288	.2 – 5 m	400 – 1000 nm	Sensor	http://www.itres.com/docs/casi2.html
HRG-SPOT 5	Spot Image	1 (PAN) 4 (MS)	5 m (PAN) 10 m (Multi)	480 – 710 nm (PAN) 500 – 1750 nm (MS)	26 days	http://www.spotimage.fr/
HYDICE	Naval Research Lab	206	0.75 - 3.75 m	400 – 2500 nm	Sensor	http://ltpwww.gsfc.nasa.gov/ISSSR-95/hydiceop.htm
HyMap	Integrated Spectronics	100 – 200 bands	2 – 10 m	450 – 2480 nm	Sensor	http://www.intspec.com/
IKONOS	Space Imaging	1 (PAN) 4 (MS)	1x1m (PAN) 4x4 m (MS)	450 – 900 nm (PAN, MS)	< 3 days	http://www.transavia.co.id/tip/geomatics/IKONOS.html
NEMO	Office of Naval Research	200	5x5m (PAN)	400 – 2500 nm	7 days	http://nemo.nrl.navy.mil/public/concept.html
Orb-View 3	Orbital Sciences Corporation	1 (PAN) 4 (MS)	1x1m (PAN) 4x4m (MS)	450 – 900 nm (PAN, MS)	3 – 10 days	http://geo.arc.nasa.gov/sge/health/sensor/sensors/orbview.html#spec
PROBE-1	Earth Search Sciences	128	1 – 10 m	400 – 2450 nm	Sensor	http://www.earthsearch.com/technology/about_probe1.html
Quickbird	Ball Aerospace Global Imaging System 2000	1 (PAN) 4 (MS)	0.61m (PAN) 2.44 (MS)	450 – 900 nm	1 – 3.5 days	http://www.ballaerospace.com/quickbird.html

2.4.3 Advancements in Mapping Techniques

The differences between remote sensing efforts for mapping reefs just a few years ago and today is revealed in widely available literature (Table 2.6) that can be categorized into four separate areas: 1) clearly defining a reef environment within a biological context, but modified to match resolution capabilities of a pre-defined sensor; 2) identifying the most appropriate techniques for discriminating the spectral wavelengths of coral reef classes; 3) designing the most appropriate field survey techniques to match spatial and spectral characteristics of selected sensors; and 4) capitalizing on the increasingly available multi-temporal image data sets to detect changes in reef features. The overriding objective of most recent studies has been to couple improved identification of environmental variables from imagery and to extrapolate the type and magnitude of environmental disturbances with both precision and accuracy.

Table 2.6. Remote sensing applications in a coral reef environment.

Author	Objective	Sensor/Satellite	Ancillary Data	Approach
Andrefouet *et al.* (2002)	Evaluation of the ability of various sensor to monitor bleaching events	Aerial photographs	Assessment of coral damage per quadrant	Minimum distance algorithm based on comparison of Euclidean distance means
Liceaga-Correa and Euan-Avila (2002)	Assessment of accuracy in bathymetry of a shallow coral reef environment	Landsat TM	Echosounded profiles	1. Single linear regression model 2. Multiple linear regression 3. Classification Techniques
Mumby and Edwards (2002)	Identification of different geomorphological reef features	IKONOS	Field data of reef features based on various spatial scales	Image filters
Palandro *et al.* (2002)	Detection of changes in coral cover	Landsat TM Landsat ETM+ IKONOS Aerial Photography	Visual estimates of coral cover along transects.	Mahalanobis distance classifications
LeDrew *et al.* (2000)	Identification of bleached corals	SPOT	Radiometric profiles over different bottom types	Getis statistic

Continued from page 17.

Author	Objective	Sensor/Satellite	Ancillary Data	Approach
Neil *et al.* (2000)	Determination of reef zones based on visual patterns	Landsat TM	*In situ* identification of major reef patterns	Supervised and unsupervised classifications
Stumpf *et al.* (2000)	Estimation concentrations of Chlorophyll, other pigments and suspended sediments	SeaWiFS	Collection of reflectance at the surface.	Semi-analytical solution using Polynomial regression of log-transformed ratio of reflectances
Allee and Johnson (1999)	Development of predictive models for chlorophyll-a	Landsat TM	Secchi disk depth estimations	Regression analysis and single linear model
Gower *et al.* (1999)	Detection of phytoplankton using a fluorescence signal from chlorophyll	MERIS	*In situ* optical properties	Radiative transfer algorithm
Siegel *et al.* (1999)	Identification of phytoplankton	Coastal Zone Colour Scanner	Collection of chlorophyll-A and gelbstoff	Colour ratio algorithms

2.4.3.1 Defining Reef Environments

Ambiguous terminology of features within a coral reef ecosystem has challenged the effectiveness of remote sensing. The problem is that accurate identification of reef features is a function of the operator's knowledge of reef characteristics and terminology as well as the spatial and spectral capabilities of the sensor (Mumby and Harborne, 1999). This poses difficulties when comparisons are drawn between different types of classified imagery; especially those with higher levels of detail (Mumby and Harborne, 1999). In an effort to minimize these effects, several authors have suggested that scientists adopt a systematic, objective, replicable classification of reef habitats (Done, 1999; Andréfouët and Claereboudt, 2000; Edinger and Risk, 2000; Phinn *et al.*, 2000; Mumby, 2001).

Couched within biological terminology, the term habitat is defined as, "An aggregation of different species of organisms living and interacting within the same area" (Wasserman, 1975). Although defining a habitat explicitly would improve classifications of remotely sensed data, the definition above implies the aggregation of variable reef structures and biological conditions at varying spatial scales that are non-decipherable with current imaging technologies (Andréfouët and Claereboudt, 2000). A solution to this challenge has been revealed in the development of a framework that combines remote-sensing capabilities and concepts from landscape ecology (Phinn, 1998). Moreover, developments in the "scaling theory" have provided direction for scaling field to image data and matching remotely sensed data to relevant state variables (Curran *et al.*, 1998). The procedure involves several steps that begin with a thorough examination of the spatially distinct natural groupings of features visible within a coral reef environment.

A study pioneering this research derives benthic classes based on an Agglomerative Hierarchical Classification of field data and Similarity Percentage Analysis (Mumby and Harborne, 1999). Results indicate that the descriptive resolution of remote-sensing techniques is still dependent upon limited decisions of the operator. In addition, the method is only useful for turbid-free images, where Jerlov 1 waters are consistent throughout the scene. Although subjectivity plays a role in defining the habitat of interest, the specifications of sensor limitations help to limit the range of subjective decisions and increase the probability of appropriate selection of the sensor (Andréfouët *et al.*, 2002).

2.4.3.2 Using the Spectral Signature for Class Discrimination

Normally, with increasing difference between the intrinsic spectral signatures of corals there is an increasing probability that coral reef features, within an image, will be successfully delineated. However, from a radiometric or sensor perspective, the relationship between electromagnetic energy of the target of interest may overlap from one species to another. The problem is that the optical signal leaving the surface of a coral is a function of that feature's pigmentation, structure, branch orientation, and internal shadowing characteristics (Holden and LeDrew, 1998; Hochberg and Atkinson, 2000; Joyce and Phinn, 2002; Lubin *et al.*, 2001; Hedley and Mumby, 2002).

Studies of coral signatures measured *in situ* typically fall into two separate categories. First, signatures are often examined as a function of variations in pigment densities that characterize the visual colour of coral species (Falkowski *et al.*, 1998). Several studies have examined the contribution of colour to measured radiance, particularly comparing the absence of colour, which results from bleaching, to coral structures saturated with zooxanthellae, a measure of health (Holden and LeDrew, 1998). Colour has also been used as a comparison measure among three coral species, five algal species, and three sand benthic communities (Hochberg and Atkinson, 2000), and as a means of differentiating between dead coral in various stages of algae colonization (Clark *et al.*, 2000). Fluorescence, a colour that results when light is absorbed in one wavelength and emitted in a longer wavelength, has also been found to contribute to reflectance received at a sensor. Five pigments have been found to fluoresce in Caribbean reef corals (Mazel, 1997). Remote detection of these pigments, using florescence, has been used for inter-species differentiation and detection of bleached colonies (Hardy *et al.*, 1992). Second, signatures are examined as a function of morphological characteristics. Reflectance values measured over varying angles and azimuths were examined to determine the bi-directional reflectance distribution function of coral species and their inter-species variation between rounded and branching types (Joyce and Phinn, 2002).

Derivative spectroscopy is the proven method for discriminating between coral signatures (Table 2.7) (Holden and LeDrew, 1998; Hochberg and Atkinson, 2000; Joyce and Phinn, 2002). First- and second-order derivatives have been effective for broad class distinction, such as live coral, dead coral, debris and algae (Holden and LeDrew, 1998; Clark *et al.*, 2000). Taking advantage of higher-order derivatives that are relatively insensitive to noise and spectral variations caused by sunlight and skylight variations (Tsai and Philpot, 1998), Hochberg and Atkinson (2000) have illustrated that fourth-order derivatives can be used to discriminate between five spectrally similar species of coral.

Table 2.7. Derivative techniques used to discriminate between features within a reef environment.

Author	Spectral Discriminating Feature	Discriminating Technique	Discriminatory wavelength peaks
Clark, Mumby, Chisholm, Jaubert, Andréfouët (2000)	Corals at various stages of mortality and algal colonization	Derivative Analysis (1st and 2nd order) of reflectance	First-order derivative: 550 nm (live from dead coral) Second-order derivative: 596 nm (live, dead, and algae covered)
Hochberg and Atkinson (2000)	Reef components, primarily coral, algae, and sand	Derivative Analysis (4th order) of reflectance	Coral: 573, 604, 652, 675 nm Algae: 556, 601, 649 nm Sand: 416, 448, 585, 652, 696 nm
Holden and LeDrew (1998)	Healthy and bleached coral	Derivative analysis (1st and 2nd order) of reflectance	First-order derivative: 500-590 nm Second-order derivative: 434, 524, 652 nm

The water column overlying the coral, and its apparent and inherent optical properties, contribute to a remotely-sensed signal (Mobley, 1994; Kirk, 1996) and thereby complicate the spectral discrimination. Radiative transfer algorithms are often applied to imagery to remove the effects caused by variable upwelling and downwelling light streams. This variability causes confusion between similar bottoms types (Ohde and Siegel, 2001) that exist at varying depths or in regions with dissimilar concentrations of suspended solids (Dekker *et al.*, 1996). Thus, the signal is not exclusively associated with a single environmental variable; rather it possesses attributes of a combination of parameters. Several studies have attempted to separate these parameters to improve discriminating abilities between coral reef features.

In 1978, a simple image-based approach to compensate for the influence of variable depth on water-leaving radiance was developed (Lyzenga, 1978). The technique involves removing scattering in the atmosphere and variation in the surface of the water, connecting depth to radiance using a linear algorithm, calculating the ratio of attenuation coefficients for different band pairs, and generating a depth-invariant index of bottom type (Lyzenga, 1978). More recent approaches have focused on expanding this technique (Philpot, 1989; Maritorena *et al.*, 1994)

(Table 2.8). Typically, however, they are founded in several assumptions that are drawn from statistical relationships between reflectance and selected attributes of the aquatic environment. Consistently throughout these techniques there are overriding assumptions that: 1) water turbidity is consistent and low concentrations of suspended solids are present throughout an image scene; 2) light attenuates exponentially with depth regardless of depth or bottom type; 3) downwelling and upwelling light streams can be characterized in an identical manner and there is no contribution by fluorescence or backward scatter; and 4) the ratio of bottom reflectance in two bands is the same for all bottom types within the scene (Newman, 2001). The assumption of log-linear attenuation with depth, in particular, is problematic for bright substrates where there may be multiple reflections between the suspended material and the surface, with the result that the rate of change of attenuation with depth changes (Newman and LeDrew, 2002)

Table 2.8. Analytical approaches to identify bottom reflectance in shallow coastal waters.

Author	Technique	Assumptions
Seafloor Reflectance Estimations		
Tassan (1996)	Linear transformation algorithm. The correlation of two wavelength bands yields the ratio of the attenuation coefficients.	Water column optical properties of deep water are similar to the ones of the shallow water area.
Maritorena *et al.* (1994)	Algorithm derived from the two-flow equations and Monte Carlo simulations	Backscattering coefficient, and vertical diffuse attenuation coefficient are not depth dependent. Bottom is a lambertian reflector (completing absorbing). Bottom contrast is exponentially attenuation in a two-way light path.
Estep and Holloway (1992)	Inverted single-scatter irradiance	Inputs for radiative transfer algorithm are provided from Case 1 Jerlov tables
Spitzer and Dirks (1987)	Two-flow radiative transfer	Waters are vertically well mixed Coefficients are depth independent
Lyzenga (1978)	Linear transformation algorithm. The correlation of two wavelength bands yields the ratio of the attenuation coefficients.	Bottom reflected radiance is approximately a linear function of the bottom reflectance and an exponential function of the water depth.

Continued from page 22.

Bathymetry Estimations		
Philpot (1989)	Single-scatter irradiance model. One scalar variable is designed to respond linearly with depth and a second to be sensitive only to variations in bottom type.	Water quality and atmospheric conditions are stable within an image scene.
Clark *et al.* (1987)	Application of a single-band reflectance model and then dual-band ratio method. Both are linear band methods.	Bottom reflectance is constant over the bottom type. Atmosphere, sea state, and other effects are uniform or constant.
Jain and Miller (1977)	Two-flow approximation model	Water of uniform optical properties and thickness Pre-defined seafloor albedo

One approach to avoiding such assumptions is to use a radiative transfer algorithm such as Hydrolight, which was designed for the purpose of computing radiance distributions for ocean water bodies (http://www.sequoiasci.com/pdf/H42Description.pdf). This time-independent model computes water-leaving radiance as a function of depth, direction and wavelength within the water. The model requires several inputs, measured closely to the time of image capture, that include: 1) absorption and scattering coefficients, 2) water surface conditions, and 3) benthic feature characteristics such as structure and depth, and sky radiance distribution. Several research groups are using this model to examine the nature of the water column's contribution to the modification of the spectral signature of a variety of coral structures.

2.4.3.3 Designing the Field Survey

The need to collect ground confirmation data (often misleadingly referred to as 'ground truth') remains a significant component of assessing the accuracy of remotely sensed imagery. For the majority of available digital imagery, it is unlikely that interpretation of reef characteristics from imagery alone will be sufficiently accurate for marine park planning and management, regardless of the operators' skill in the identification of marine habitats. Although the ground confirmation information comes at a high cost and the acquisition is often a lengthy process in comparison to airborne and satellite imaging, adequate field surveys can clarify confusion and avert inappropriate planning strategies based upon poor information.

Field survey is an essential ingredient of image analysis of coral reef environments for three primary purposes: 1) to define habitats of interest; 2) to locate areas that represent these habitats from which spectral signatures may be taken; and 3) to test the accuracy of a classified image (Green *et al.*, 2000). A variety of field survey methods may be employed (Table 2.9).

Table 2.9. Current field based techniques used to monitor coral reef characteristics.

Method	Description	Strengths	Limitations
Measurement of Ambient Environmental Parameters	Data reflect the health of a reef and includes temperature, salinity, turbidity, light penetration, cloud cover and wind	Objective analysis that provides standardized measures	Expensive and time-consuming Requires access to instruments specific to the environment
Manta Tow Survey	This semi-quantitative technique is used to assess broad changes in the benthic communities of coral reefs where the unit of interest is often an entire reef	Visual assessment of large areas of reef within a short time. Good for determining the effects of large-scale disturbances	Accuracy and precision are a function of the identification abilities of the data collector The driver who views the reef from above the water controls tow-path
Line Intercept Transect	This semi-quantitative technique is used to assess the sessile benthic community of coral reefs	Requires little equipment and is a reliable and efficient sampling method for obtaining quantitative percent cover data	Potential bias estimate of the proportion of the total area covered Difficult to standardize some of the life form categories
Permanent Quadrant Method	Designed to monitor change in the biological condition, growth, mortality and recruitment of corals in a permanently marked area	Sampling is non-destructive. Detailed and careful observation, photography, and mapping of the fixed area provides a detailed record	Method is slow and can be difficult with strong currents Requires a flat area and coverage is small
Coral Reef Fish Visual Census	Assessments are conducted along transects that are censed during daylight hours using SCUBA. Reef fishes are assessed using abundance categories, and individual counts allow estimates of standing stock	Quantitative and qualitative nondestructive method utilizes a minimum number of personnel The same area can be resurveyed through time	Observers must be well trained and experienced. Fish may be alarmed by the presence of divers and swim away

Compiled from English *et al.*, 1997.

2.4.3.4 Capitalizing on Multi-Temporal Coverage

Following the launch of Landsat 7 ETM, a series of images of coral reefs from various regions have been collected systematically as a part of the Long Term Acquisition Plan (Gash *et al.*, 2000). This was the first major attempt to target isolated coral reef ecosystems repetitively. Users are being afforded a unique opportunity to focus their energies on change detection methods without the complications associated with mixing different image types of varying spatial or spectral specifications (Palandro *et al.*, 2002).

Andréfouët *et al.*, (2001) made an early assessment of the potential of the Landsat 7 ETM+ to detect change within a reef environment. Images were acquired within a brief time frame in which there was no major disturbance to reefs. This enabled an assessment of the stability of the images through time and allowed estimates of biases that may be associated with change detection strategies. The authors suggested, with the assumption that areas are large enough to provide an unmixed signal, that there is difficulty in detecting changes from one object to another even when the acquired images have identical specifications. The reason for this is that any occurring change must be visible and cover a large enough areal extent to saturate pixels. Effects of a hurricane, for example, would be easily identified since it destroys living structures and transforms a heterogeneous environment to a homogeneous platform. Therefore, depending on the physical or biological shift within a coral reef ecosystem – disturbance, phase, or strategy – spectral differences may or may not be dissimilar enough to be detected. Un-mixing techniques are cited as a potential solution to detect intra-pixel changes, but may be only realistic for no more than three classes such as sand, background, and foreground.

Several change detection techniques used on images of coral reef environments are derivatives from land- or ice-based techniques (Lunetta and Elvidge, 1999). The Getis statistic, for example, can be used to examine the change in reef homogeneity. This measure considers the value of the reflectance within a single pixel and its relationship between that pixel and the surrounding reference pixels. It has been hypothesized that a healthy coral reef ecosystem will be heterogeneous, and display negative autocorrelation, while a disturbed reef similar in bottom type over a large area will be spatially homogeneous and display a positive autocorrelation (LeDrew *et al.*, 2004). Principal components analysis (Mas, 1999) and the Mahalanobis distance classification (Palandro *et al.*, 2002) techniques are regularly used prior to comparing images to detect change. It is generally accepted that there are four aspects of change detection that are important when monitoring natural resources: 1) detecting that changes have occurred, 2) identifying the nature of the change, 3) measuring the areal extent of the change, and 4) assessing the spatial pattern of the change (Klemas, 2001).

2.4.4 Obstacles to Successful Mapping of Coral Reef Environments

In the past there has been the notion that remote sensing of coral reefs was being oversold (Green *et al.*, 1996). It is evident today, however, that aerial and digital mapping tools may offer some of the most important data sources for management strategies. Nevertheless, prior to undertaking the task of mapping a coastal shoreline inhabited by reefs, it is important that the limitations of remote sensing techniques be understood. The limitations to remote sensing can be grouped into three categories: 1) fundamental limitations; 2) operational limitations; and 3) user limitations (Table 2.10). Fundamental limitations are those that exist simply because of the nature of the environment. For example, the presence of water over coral complicates a remotely-sensed signal. Operational limitations include technological limitations or mismatches that exist between field and image data. User limitations arise from the complexities of imagery costs and appropriateness, as well as from communicating information to the user. In all cases, current research is addressing potential solutions that should provide a clear assessment of the limitations of using remote sensing technologies for coral reef management.

Table 2.10. Limitations that prevent accurate identification of reefs within satellite imagery.

Limitation	Potential Solution
Fundamental Limitations	
Variable Water Attenuation	Radiative transfer theorem
Variable water composition through time and space	Non-linear multi-layered algorithms
Variations in depth	Non-linear algorithms
Limited wavelength depth of penetration	Hyperspectral sensors
Heterogeneous bottom	Spectral unmixing algorithms
Air-water interface	Analytical techniques
Variable atmospheric conditions	Radiometric correction
Cloud cover	Masking techniques
Isolated reefs	Airborne imagery
Operational Limitations	
Course spatial resolution	Spectral unmixing
Course spectral resolution	Hyperspectral sensors
Disparity between date of image acquisition and *in situ* data collection	Analytical formulae
Satellites do not collect data in targeted area	Airborne imagery
Lack of *in situ* data	Combined analytical techniques and historical imagery
User Limitations	
Inadequate remote sensing knowledge on the part of managers and planners	Communication between experts and users
Differences between scientist generated image accuracy and required manager image accuracy	Pre-image consultation between scientist and user
Disparity between information images provide and information needed by managers	Consultant agencies
Information needs of coastal users are site specific	Variations in image displays
Cost of imagery, hardware, and software	International cooperation

2.5 MANAGEMENT APPLICATIONS OF REMOTELY SENSED INFORMATION

Remotely-sensed images are powerful visual tools for display and communication. Indeed, several arresting coffee table books have been produced from exotic satellite and airborne imagery (Scubazoo, 2007; Sheppard, 2002; Sprung, 1999). Such images may be the basis of a powerful persuasion for remedial action regarding coastal resources; however, the manner in which these visual tools can be used by coral reef managers remains in question. In a Western context, where remote sensing technologies thrive, remotely-sensed images have been incorporated into agencies, corporations, and academic teaching institutions for the purposes of: describing weather conditions, examining topographical variations, and highlighting terrestrial or aquatic features of interest. Outside of a digital context, airborne and satellite images are used for purposes other than those intended by remote sensing scientists. In most instances, satellite images are primarily used for visual appeal, as opposed to functional or operational purposes. Thus, a considerable challenge remains – interpreting meaning and value from satellite imagery and transferring that information to people who reside outside the digital context.

2.5.1 Communication of Remotely-Sensed Coral Reef Information

In attempting to communicate remotely-sensed information of coral reef features, a historical dichotomy between academic and applied research becomes evident. The dichotomy is this: the analysis of airborne and satellite images are typically coordinated through personnel and facilities within developed countries, while the application of the product occurs within socially and culturally separate regions. Coral reef remote sensing scientists, to date, rarely undertake research with the purpose of communicating and then applying their findings in an effective manner in regions that are socio-culturally distinct. To be effective, the analysis should involve the clients from the beginning, and this should take place at the community level (White, 1994). In reality, the onus is often placed upon the end user, local community member, manager, or planner in the client's region, to interpret the visual representation of coastal elements and form a conservation strategy appropriate to their setting. With the absence of funding and, often, training in these financially-challenged regions, users must depend on images generated by traditional "Western science". As a result, the full implementation of remotely-sensed images is not realized because of the lack of information synergy between mapmaker and map user.

2.5.2 Obstacles to Successful Communication of Remotely Sensed Information

Communication defined, is simply "…to convey information."(Merriam-Webster, Online, 2008). Within the context of typical applications of remote sensing, communication may be viewed as conveying the relevant quantitative information interpreted from an airborne or satellite image. Effective or successful communication of information, derived from imagery, presumes that the end-user understands the conveyed information (Populus *et al.*, 1995). It is the development of this understanding that becomes the challenge in successfully applying remotely-sensed data for management plans in developing countries. The effort expended on communication can make the difference between success and failure (Erdmann, Personal Communication, 2004). 'Parachute science', which eliminates or reduces the amount of contact between a science and manager, remains a common method for assessing management strategies and deciphering the most appropriate application of the technology. Other factors that challenge effective communication of remotely sensed information are summarized in Table 2.11.

From a mapmaking standpoint, accurate interpretation of features extracted from satellite imagery, and their interconnectedness, often requires experienced operator knowledge and skill. A study involving the transfer of technology reports that experienced personnel is an essential factor if the technology is to be applied successfully (Specter and Gayle, 1990). In addition, extensive field work experience and knowledge of the key drivers of ecosystem change and set-up are essential for not only designing the field survey, but also melding this information with satellite information for validation purposes. From a map user standpoint, traditional knowledge influences a person's ability to interpret the satellite image. User attitudes, knowledge, and perspectives drive the interpretation and understanding of visually depicted elements (Specter and Gayle, 1990). In most traditional societies, for example, local people do not fully understand coral reef environmental issues or the scientific explanations of ecosystem interrelationships (Veitayaki, 1998). As a result, specialist knowledge and user understanding and perspectives deter and often halt communication of information from intensive remotely-sensed programs.

Table 2.11. Major obstacles to communicating remotely-sensed information to the user.

Obstacle	Solution
Technological Dimension	
Image development: Specialized techniques and processes Data volume	Involvement of experienced personnel familiar with calibrating and correcting airborne or satellite imagery Appropriate hardware and software processing capabilities and personnel trained in data reduction techniques
Field data collection: Complex linkages between multiple environmental variables	Involvement of trained personnel familiar with the dynamic physical and biological processes within a coral reef environment Involvement of local people in identifying targets of interest
User Dimension	
Visual perceptions: User's unfamiliarity with visual depiction of elements	Construction of alternative visual displays of information Incorporation of traditional forms of communication mediums
Interpreters knowledge: Different socio-cultural benchmarks between user and communicator	Involvement and cooperation of local community members and image operators from identification of objectives to final stages of image construction

Modified from Specter and Gayle, 1990.

2.5.3 Importance of Incorporating Local Knowledge

The technical process of accurately imaging coral reefs, referred to as the 'construction stage', begins with defining the objective of the study and deciding on the most appropriate and feasible image type to meet pre-determined goals (Green *et al.*, 2000). In the case of restricted budgets, or limited access to the region, archived data may be selected as the primary data for analysis. Regardless of whether archived or ordered images are selected, operators target images that possess minimal cloud cover and best represent the feature of interest in both spatial, spectral, and temporal dimensions (Green *et al.*, 2000). If images that include the desired information are unavailable and/or if data for a particular event or season is required, then a scheduled flyover is planned, taking into consideration costs and image processing turn-around time. *In situ* field data may be collected simultaneously with image capture to evaluate the accuracy of the image and to enhance the information interpretation (Green *et al.*, 2000). Once both field and image data are gathered, corrections and integration of data sets begin and a final image is produced with a defined specified level of accuracy and information content (Lillesand and Kiefer, 1994).

During these steps, local communities can be involved; however, this introduces complexity and slows the process of image construction (Veitayaki, 1998). Nevertheless, local communities' involvement in the 'construction stage' considerably improves the relevance and practicality (White, 1994). When the objectives of the study are being defined, local community members should identify their own research needs (Johannes, 1998; Elliot *et al.,* 2001; Wismer *et al.* 2005). Often these needs are in conflict with those of the technically trained who often wish to: 1) address purely scientific questions concerning variables that have remained largely unexamined; and/or 2) tackle specific organizational directives from the funding agency. Although scientists cannot be held to blame for the direction of academic research, managers would welcome almost any scientific information and would benefit from opportunities to define their own agendas (Hof, 2002).

Once local communities are involved from the beginning stages of the project, on-going dialogues during subsequent stages of image construction can continue and increase the appropriateness of the final product. Local communities will benefit from the process by increasing their knowledge of environmental variables and linkages, and by better understanding how pre-determined objectives will be displayed, all the while appreciating the amount of time and effort required for variable levels of image accuracy (Turner and Klaus, 2005). Although involving local communities creates complexity, it is essential to the planning and implementation of appropriate resource management strategies (Cooke, 1994). It is evident that there are considerable issues to face when bringing together remotely-sensed information and local knowledge, but incorporating a series of guidelines (Newman and LeDrew, 2004) may heighten the successfulness of the integration process and bring about greater utilization of remotely sensed information.

2.5.3.1 Building an Image with Local Input

Communicating environmental information using satellite imagery or an image-based map is not a universal strategy (Johannes, 1981). For example, on several islands within Indonesia, it is typical for the local managers to learn about spatial and temporal changes to coral reef features without the aid of visual devices. Avoiding spatial proximity issues, features are described in the form of lists emphasizing type and abundance (World Bank, 1994; Cesar *et al.*, 1997; Fearnside, 1997; Pet-Soede *et al.*, 1999). When working with geographic maps or images, different people obtain different amounts and kinds of information from them. This is the result not of the subjectivity of the information, but rather the different degree of the viewers' ability to extract information There are differences between the interpreters' image of reality and parts of reality that have been mapped, and what actually exists (Salichtchev, 1977). Therefore, remote sensing operators are challenged to illustrate complex environmental linkages in a simplified and relatively accurate manner to users who, in some cases, are less familiar with visualizing spatial patterns.

Building upon cartographic principles, it is possible to improve the effectiveness of communication of remotely-sensed information for the problem-at-hand (Veitayaki, 1998). Cartography as a practice is almost second nature to image analysts. It is a form of communication that presents locations and environmental features with scaled spatial proximities in a two-dimensional structure (Bartels and Beurden, 1998). In essence, maps or images are conceived as elements in a process of communication that involves both the mapmaker and map user (Eckert, 1977). The role of cartography in communicating remotely-sensed information is rooted in the mapmaker's ability to express features in a solid, generally accepted visual representation that promotes successful comprehension by the user. Basic elements that include: 1) symbology; 2) classes and class boundaries; 3) colours; 4) scale and projection; and 5) basic map features (Bartels and Beurden, 1998) are used to express information to the user in a social-culturally appropriate manner. For this discussion, the critical concepts are 'generally acceptable' and 'culturally appropriate'. This means that several culturally relevant issues should be explored prior to product design (Table 2.12) because of their ability to significantly influence the success of image communication.

Table 2.12. Issues to consider prior to undertaking map construction.

Issues	Questions
Attitudes, Perceptions, Beliefs	How do people perceive and value the marine environment, and its use? Who supports and who opposes visual representations of coral reef data, and why? What do people expect of images ecologically and socioeconomically, over the short and long terms?
Taboos	How do people perceive the organisms within their environment? Which reef organisms are considered sacred, and what is their story? What types of criteria are in place when a "supernatural" feature is present?
Use Patterns	Who uses the marine environment in and near the identified boundaries, and how? What do resource users know about the resource and its use? How might resource users, groups, and communities adapt, thus changing their use patterns in the future? What are the socioeconomic implications, including distribution of costs and benefits, of the above changes?

2.5.4 Remote Sensing for Management: Case Study in Savusavu Bay, Fiji

An experience of communicating image-based information in Fiji may illustrate the difficulty of understanding the cultural context for spatial information. In a paper, LeDrew *et al.* (2004) discussed the extensive damage of a coral reef in Savusavu Bay of Fiji as a consequence of overflowing of settlement lagoons of a gold mine during a major precipitation event. SPOT images before and after the event were obtained. The site was visited and the damage recorded on video. A basic form of change detection analysis was performed to highlight regions that could be identified as stressed. Colour-coded maps were generated from the analysis. From this experience in Fiji during prior field experiments, it was understood that the village chiefs were the ultimate authority in management of the reefs through the village's historical reliance upon reef resources. Researchers decided to hold a 'town-hall' type of discussion with the villagers and the chiefs in the region affected by the coral damage, and another village on the other side of the Bay that was only peripherally affected by the event. This village was also close to the main town of Savusavu and inhabitants had interacted with tourists for many years through their employment at the resorts. The gold mine was far from any tourism influence. The villagers in the Savusavu town region could understand the concept of reef damage, had a good grasp of 'Western' approaches to reef conservation and could identify their location on the map. The villagers in the region of the gold mine showed little interest in the map and associated discussion, even though they appeared to understand the language spoken. They were fascinated, however, by a video of the damaged reef. But they expressed no concern, only amusement at the moving pictures. There was no discussion of the nature of the damage of the impact on their livelihood, possibly since it was heavily supported by employment in the gold mine.

The researchers learned that the traditional management of the reef resources is based upon taboos (Knight *et al.*, 1997). The concept of taboos exerts a pressure on local communities that directly influences their impressions and use of marine resources. For example, the concept of sacred ground identifies sacred fishing regions where particular rules are abided by. There is an association with supernatural forces that ensures fishing grounds are respected and protected at all times, even with the absence of enforcement officers. If a certain predator species is caught, for example, fishing stops. According to the villagers, if they do the correct things their gods, will provide them with what they have asked for (Jennings and Polunin, 1996). In reality the predator is there because of a downturn in the "health" in the coral reef, which, some time before, was associated with lower fish catches and stress on the villagers. In Fiji, it is essential that such cultural traditions be understood to avoid visual representation of features that are respected and valued in traditional ways. It is possible that with the reliance upon gold mine work, the villagers have lost some of their cultural connections with the reef (others more qualified would be able to verify this). A lesson from this experience was that the colourful map had no impact because maps were not part of their normal interaction with the local environment. If their taboos were integrated in the map to illustrate the problem and potential remedial action it might have been possible to strike a resonance with their historical experience.

This example illustrates the importance of understanding local culture and local knowledge in effective communication. It is generally understood that, with such close ties to the environment an inherent understanding belongs to local people who have tended to ensure the long-term sustainability of their resource base (Veitayaki, 1998). The advantages to understanding the impact of local knowledge in communication are that: 1) the local people are directly aware of the current status of the marine resource on which they depend, 2) the local people possess an inherent temporal knowledge of patterns and changes to variables within the marine environment, and 3) the local people are valuable resources for developing monitoring and managing strategies. Is it also important to be aware of the disadvantages, which may include: 1) the local knowledge is contained in a verbal medium and is unverified, 2) the attitudes of local people towards their resource may not include a positivistic conservation outlook, which can discourage proper management plans, 3) if the local knowledge is exclusive to the area, there may be minimal overlap between regions within small spatial proximities, 4) the variability of human and physical events from one shallow coastal water environment to another, may prevent the incorporation of an approach that was deemed successful elsewhere, and, 5) in regions where demands on resources have, historically, greatly exceeded their sustainable capacity, it remains uncertain whether or not traditional knowledge will be of any use to management strategies (Veitayaki, 1998). Clearly, there are fundamental signs and signals for understanding any social-cultural environment, and familiarity with these coded messages permits familiarization with the 'communicating' arena.

2.6 CONCLUSION

The value of remote sensing lies in its ability to improve decisions and negotiations by providing better information to various stakeholders so that more alternatives can be generated and evaluated. The goal is to bring tangible impacts to the ground. Improving management decisions, however, runs counter to the conventional scientific value system where solutions are often selected that bear minimal relevance to local stakeholders' perceptions of the problem. However, there is strong evidence, and a slowly increasing number of examples in the scientific literature, where research that includes on-the-ground involvement is a key to expanding the role and application of remotely-sensed information in developing nations. Otherwise, supporting fishers as managers with site-, issue-, and context-specific information may be a more appropriate approach, rather than developing generalized habitat maps that describe coarse-scale habitat information.

Remote sensing alone will not solve the problems faced by coastal communities struggling to secure a balance between marine resource exploitation and conservation. However, remote sensing has a role to play, and there is an urgent need to strengthen the communication basis for applying remotely-sensed information for marine resource management plans in developing nations. Yet the potential for remote sensing to contribute to specialized plans, particularly in small island states, will not be realized by simply gathering more satellite imagery or conducting more field surveys for validation and algorithm development. Realization and utilization will come with on-site research that delivers appropriate products that have evolved through numerous meetings and discussions with local community members, planners, managers, government officials, and members of a local marine resource management board. Successful management plans are ones that have adopted technological information because of its appropriateness to the management plan, which has been interpreted by the researcher in a fitting manner, and has been continuously discussed with local management authorities. Research must become part of management – an exercise that involves an understanding of how the remote sensing processes work, where they do not, and how they can be interpreted, adapted, and communicated – a task that challenges scientists to 'design with culture'.

CHAPTER THREE:
RESEARCH APPROACH

In this chapter, the research approach is described, including descriptions of the data collection techniques, processing, and analysis procedures for each stage of the strategy. Numerous illustrations are provided to summarize descriptions. Following a description of the research approach, a research timeline is provided. The research approach described herein began in 2001. Field data were collected in Bunaken Island, Indonesia. Data were collected in subsequent field periods, 2002 and 2004. Next, the tools that were used to collect data in each of the field periods are described. The second half of this chapter describes each of the stages of the strategy that was developed through this research, in detail.

3.1 RESEARCH APPROACH

Mapping coral reef environments using satellite imagery has long been a response to the coral reef crisis. The non-invasive, rapid, and synoptic characteristics of remote sensing make the technique appealing and desirable to both scientists and managers, but, despite the recognition that habitat maps can contribute positively to coral reef management, it remains an underutilized resource. There are numerous suggestions for why this is the case; however, there have been no scientific studies that assess why coral reef habitats maps are not being used to address specific coral reef management concerns. This research set out to address this issue by developing a strategy that targets habitats in a remotely-sensed coral reef habitat map and modifies the appearance of the map to address stakeholder-specific management concerns. The strategy developed here is founded on the traditional remotely-sensed mapping process, although it differs significantly in a major aspect: the strategy enables stakeholders to identify habitats that address their management concerns and to identify how the habitats should be illustrated. The researcher developed a set of methods that would ensure stakeholder input was sought and integrated.

The strategy includes four stages; the first stage is to develop a habitat map; the second stage is to acquire stakeholder feedback to the habitat map; the third stage is to link the stakeholder feedback with habitat data; and, the fourth stage is to illustrate the linked information using stakeholder-identified cartographic elements. The stages are sequential and the strategy, as a whole, presents a clear and logical structure to permit replication (Table 3.1).

Table 3.1. Summary of objectives and methods used in each stage of the strategy.

Stage	Objective	Method(s)
1	To develop a coral reef habitat map using traditional remote sensing mapping procedures that involve collection of a satellite image and followed by *in situ* habitat data collection and use of habitat data to guide a supervised classification of the imagery.	Acquire an IKONOS satellite image. Collect information about habitat data from randomly selected 4x4 m areas and along transects. Mask clouds, boats, docks, land, and deep water. Apply a water column correction algorithm to the data. Conduct a supervised classification, using the field data to guide selection of habitats.
2	To investigate stakeholder receptivity to the coral reef habitat map that was developed in Stage 1.	Identify stakeholder groups and key contacts within each stakeholder group. Conduct informal interviews and focus group discussions with each group. Request feedback from stakeholders on map content, map presentation, and map applicability to current and future coral reef management projects.
3	To link map applicability information (from stakeholders in Stage 2) with habitat information (from coral reef habitat map in Stage 1).	Deconstruct information about map applicability acquired in Stage 2 to coral reef habitat data. Match the deconstructed coral reef habitat data with habitat data that is discerned within the IKONOS coral reef habitat map. Identify the 'degree of association' between information provided by stakeholders and information provided by the IKONOS habitat map.
4	To illustrate linked information (Stage 3) in a form and language that is appropriate to each stakeholder group (from stakeholders in Stage 2).	Deconstruct information about map content (from Stage 2) into separate categories (based on stakeholder group). Isolate habitat data (from Stage 3) and map. Overlay deconstructed information about map content.

The four stages were developed to fit within the existing context of both coral reef remote sensing and small island stakeholder-driven coral reef management: numerous remotely-sensed habitat maps are currently available for small islands within developing countries and, in

Indonesia, stakeholders have moved into a role of decision making, especially decision making related to coastal management. The strategy presented here assumes a remote sensing scientist perspective; the scientist uses his/her knowledge to apply a habitat map to local coral reef management problem. One significant difference in this process, from traditional coral reef remote sensing perspectives, is that the scientist engages in active research and collects and assesses qualitative data. Despite the challenges of conducting both physical and social science research, the process involves implementation of disparate methods, and integration of the results from these methods. In summary, the strategy developed in this dissertation is founded on the following contexts: coral reef remote sensing scientific perspective, active research, stakeholder participation, and qualitative and quantitative data collection (Figure 3.1).

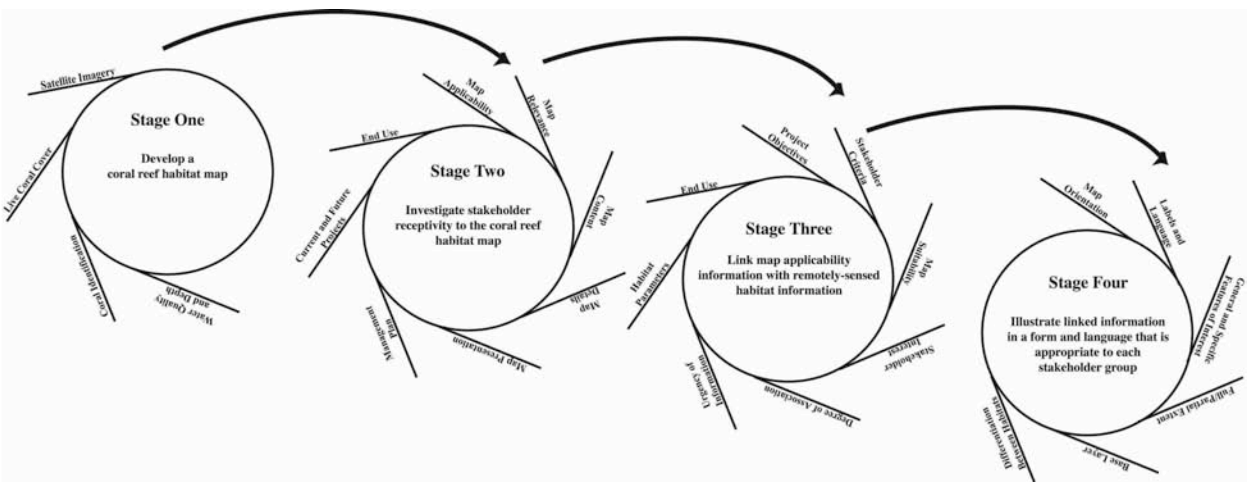

Figure 3.1. An illustrative depiction of the stages within the strategy.

The final product of the four-stage process is a management map. The management map is considered to be an enhancement of a habitat map: a management map identifies habitats of interest to stakeholders and uses a language that permits recognition and understanding by stakeholders. Unlike a habitat map, a management map is both management- and stakeholder-specific. This dissertation concludes with an evaluation of the habitat and management maps to provide input to coral reef management projects.

3.2 RESEARCH TIMELINE

Prior to and in between data collection for this research, the researcher participated in several independent remote sensing projects. In May 1998, February 1999, September 2002, and July 2003, traditional coral reef remote sensing mapping studies were conducted in Fiji, US Virgin Islands, Palau, and British Columbia, respectively. Although data for numerous variables were collected, such as inherent and apparent optical water properties and/or coral/fish biodiversity, data on coral reef habitat types were consistently collected for the purpose of developing a baseline habitat map of the study area. These projects permitted the researcher to gain an understanding of the traditional mapping process, the habitat types that could be mapped using high-spatial satellite imagery, and an awareness and appreciation of local coral reef impacts and stakeholder responses to these impacts. The awareness and knowledge gained from these experiences drove the development of the process presented in this dissertation and contributed to the development of the methods. Data specific to the research presented in this dissertation were collected over three separate field seasons: May-August 2001, May-August 2002, May-October 2004. An overview of the data collection and analysis periods is presented in Figure 3.2.

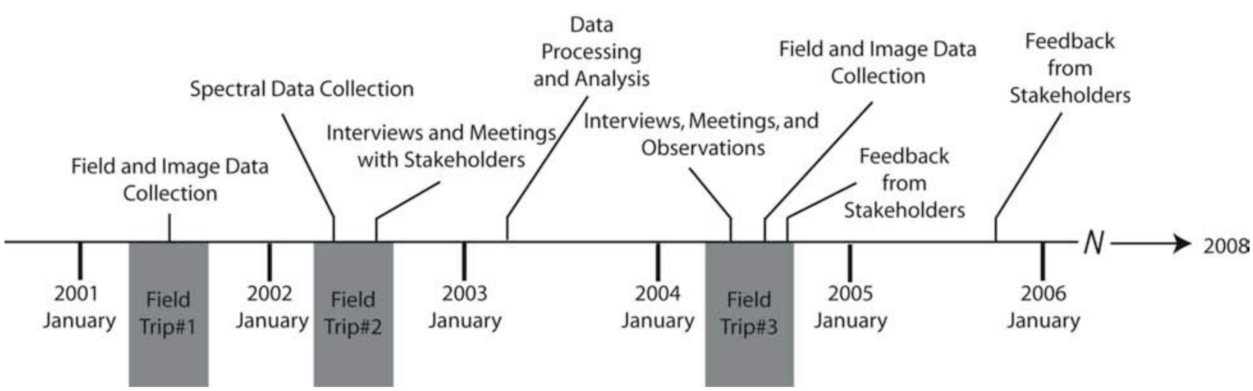

Figure 3.2. Research timeline with shaded areas showing time in the research site.

3.3 RESEARCH METHODS

The research methods are grounded in the broad methodological fields of quantitative and qualitative research. Because the methods are described in considerable detail in each stage, only a general description is provided here. The term ‘researcher’ herein refers to the author of this document and the sole researcher for the information presented here. Additional terms used in this dissertation are described following the initial use of the term.

3.3.1 Quantitative Tools

Quantitative data for this research included image and field data. First, two 4-metre multispectral and 1-metre panchromatic IKONOS satellite images of Bunaken Island were captured for July 7^{th}, 2001 and June 6^{th}, 2004. Both images were acquired with full 11-bit radiometric resolution and at 18-degrees off-nadir angles. Both images were acquired under conditions of light haze, < 20% cloud cover, and minimal surface water roughness. Image preprocessing included radiometric and geometric corrections, which were conducted by Space Imaging.

Field data included a library of ground observation points that were collected in both 2001 and 2004 for the purpose of sea-truthing the satellite image. A ground observation point represents one point on the ground, covering an area of 4 x 4 metres, from which geographical coordinates, water depth, substrate type and cover, and photographs were collected. Most points were selected randomly throughout all geomorphological zones (reef flat, reef crest, and reef slope) and all management zones (core, tourism, and general). Some points lie at half-metre intervals along transects that were placed over areas of interest, beginning at the shoreline and extend to the reef crest. Along transects, video surveys were conducted.

3.3.2 Qualitative Tools

Qualitative data were collected by the researcher and field research team, which consisted of personnel from the Natural Resource Management (NRM III) staff. The Office of Natural Resources Management is stationed within USAID and "… is tasked with the coordination and management of Agency programs that affect the sustainable use of natural resources: forests, biodiversity, land and water" (http://www.rmportal.net/groups/nrm/). NRM III (Indonesia) is one of 9 partners in an NRM collaborative program between the government of Indonesia and the United States of America. NRM III was in operation until October 2004, at which time the World Wide Fund for Nature took on NRM III responsibilities.

Qualitative data gathering tools included informal interviews, focus groups, and participant observation. The tools were selected using assistance from on-site researchers and from the Socioeconomic Manual for Coral Reef Management (AIMS, 2000). The qualitative data collection processes followed the principles laid down in Participatory Rural Appraisal (PRA) methodologies (Chambers and Guijt, 1998). Qualitative data were collected in 2004 and the total number of respondents interviewed was 36, the total number of focus group discussions was 5, and participant observation was conducted regularly throughout the field period.

3.3.3 Data Collection, Processing, and Analysis by Stage

A description of each stage including the data collection methods, processing, and analysis is provided in detail below. Figure 3.3 provides an overview of the inputs and outputs used in each stage, while the remaining figures in this chapter outline the steps and decision used at each stage.

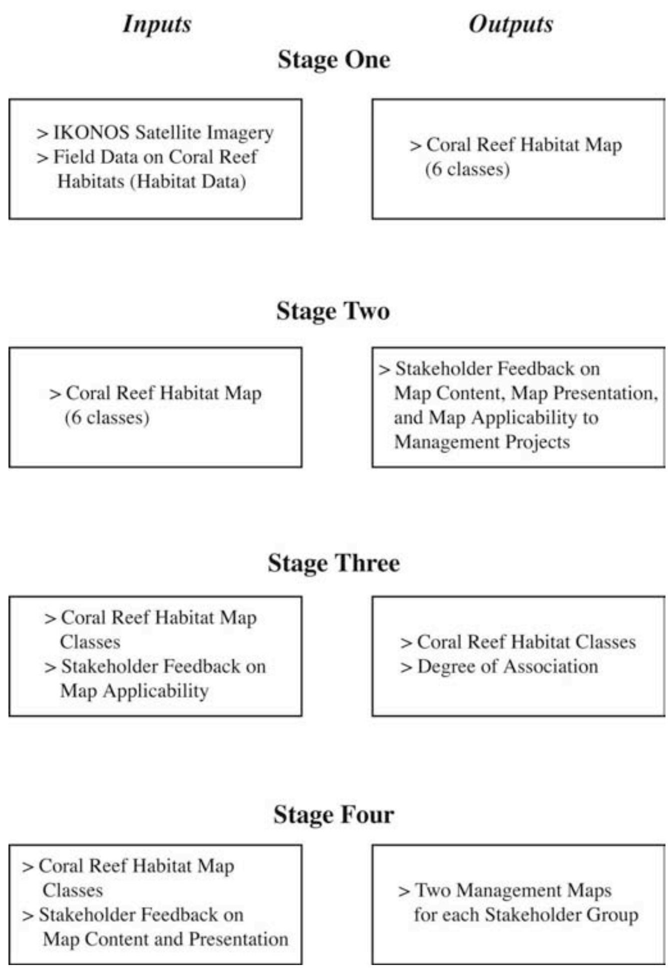

Figure 3.3. Inputs and outputs for each stage of the strategy.

3.3.3.1 Stage One: Development of a Remotely-Sensed Coral Reef Habitat Map

A standard method for mapping coral reef habitats using IKONOS satellite imagery is described here. The objective is to develop a remotely-sensed coral reef habitat map with an overall mapping accuracy > 80%. Data include a 2001 IKONOS satellite image and ground observation points. The ground observation points are used to drive a classification scheme, which begins with an atmospheric correction, and then a water column correction. The Region of Interest (ROI) separability tool is used to spectrally differentiate between habitat types, thereby reducing the initial number of habitats to 6 types. Image data are processed in ENVI (Version 4.1) imaging software, while MS Excel is used to compile and organize the ground observation data. This procedure was repeated for IKONOS satellite imagery that was acquired in 2004. Ground observation points were also collected and 6 habitat types, the same habitat types identified in the 2001 image, were used to drive the supervised classification. Next, a change detection analysis was performed to identify the change (increase/decrease/no change) per pixel in the coral and seagrass classes. The steps and decisions employed in this stage are described in Figure 3.4.

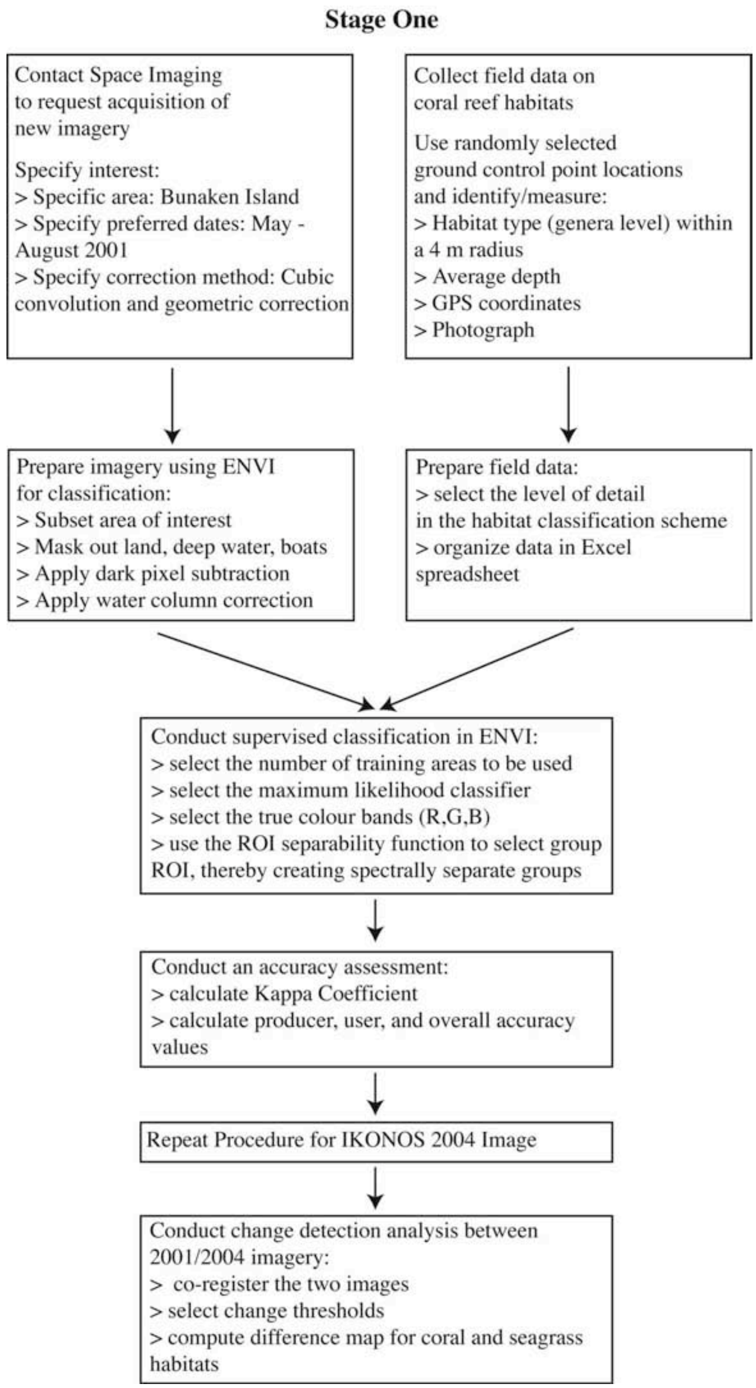

Figure 3.4. The steps and decisions used in stage one.

3.3.3.2 Stage Two: Stakeholder Receptivity to the Habitat Map

The methods described in this stage are designed to investigate stakeholder receptivity to the habitat map developed in stage one. Qualitative gathering tools include informal interviews, focus group discussions, and participant observations to investigate stakeholder receptivity to map content, map presentation, and map applicability to current and future management projects. Informal interviews involve the use of an informal questionnaire that contain open-ended questions to obtain the undirected opinions of respondents. Each qualitative tool utilized the habitat map, which was used as the centerpiece of discussion. To the best of the researcher's knowledge, the methods presented here are unique to the field of coral reef remote sensing because they involve actively investigating stakeholder receptivity to a coral reef remotely-sensed habitat map. Both steps and decisions used in this stage are identified in Figure 3.5.

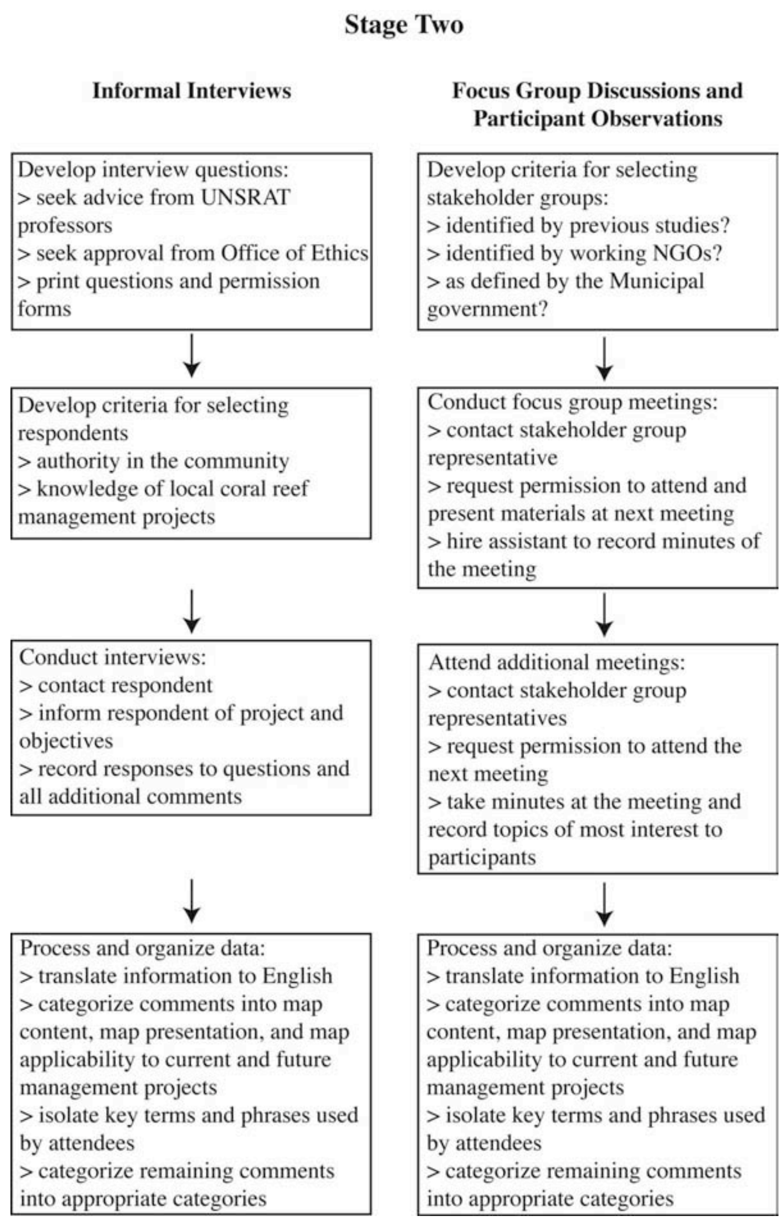

Figure 3.5. The steps and decisions used in stage two of the strategy.

3.3.3.3 Stage Three: Linking Coral Reef Management Projects with Remotely-Sensed Habitat Data

The methods in this stage provide an objective and systematic approach to deconstructing stakeholder feedback to the habitat map: to indicator(s) and associated spatial and temporal characteristics, and then to linking this information to mapped habitat types and associated habitat spatial and temporal scales. The researcher and research assistants deconstruct the feedback by using knowledge of the physical and social environments, and identify a degree of association between indicator and habitat. The ‘degree of association’ provides a means of quantitatively assessing the strength of association between indicator(s) that were identified by stakeholders and habitat(s) that were delineated in the IKONOS satellite imagery. The steps and decisions used in this stage are identified in Figure 3.6.

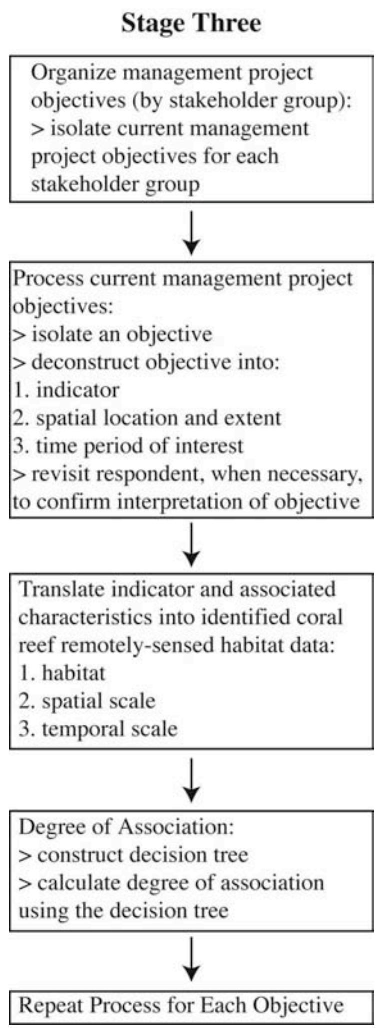

Figure 3.6. An outline of the steps and decisions used in stage three.

3.3.3.4 Stage Four: Illustrating Remotely-sensed Habitat Data and Cartographic Elements

A multitude of techniques is available for applying cartographic elements to a habitat map; however, the methods presented here focus on integrating general structure, reference features, habitat type illustration, and map format. Stakeholders created these categories: each category was identified as ‘critical’ to recognition and understanding of the mapped information. The categories are then used as a guide in the development of management maps. The final steps and decisions to constructing a management map are outlined in Figure 3.7.

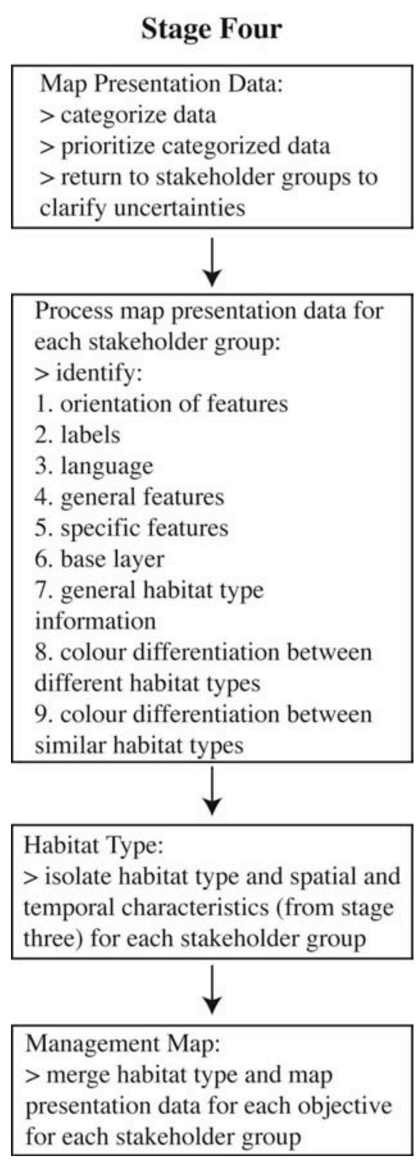

Figure 3.7. The steps and decisions made in the development of management maps in stage four.

CHAPTER FOUR:
STUDY AREA

In this chapter, a description of Indonesia, the geography and ethnicity is provided, and follows with a description of the political history. Next, the marine protected areas management efforts are detailed, focusing on the formation of the Bunaken National Park Management Advisory Board and Bunaken Island zonation plan. A description of Bunaken Island, the research site, the geography, the stakeholder groups, and the management efforts concludes the chapter.

4.1 INDONESIA

4.1.1 Geography

In 2003, the Government of Indonesia published data indicating that the archipelagic nation of Indonesia consists of 17,000 islands. Ten years earlier, several other publications noted that the country of Indonesia consists of 13,667 islands, but projected up to 18,000 (Frederick and Worden, 1993). Today, the total number of islands still remains in question, but most studies agree that the total area claimed by the nation is 7.9 million square kilometres (Frederick and Worden, 1993 (Figure 4.1). The total land area is approximated at 1.92 million square kilometres, which includes five main islands, two major archipelagos, and sixty smaller archipelagos that are occupied by the majority of Indonesia's population (Frederick and Worden, 1993). Located on the main island of Java is Jakarta, the capital of Indonesia.

Figure 4.1. Location of Indonesia relative to surrounding countries (Source: Google Earth).

Surrounding these islands, Indonesia's water temperatures are relatively uniform with moderate temperatures on land (Frederick and Worden, 1993). Indonesia's climate is tropical and hot, except for several regions located in the higher mountains. Relative humidity ranges between 70 and 90 percent and winds are moderate and predictable (Frederick and Worden, 1993). Monsoons arrive from the south and east in June through September and from the northwest in December through March, thereby defining the dry and wet seasons, respectively. The dry season is influenced by the Australian continental air masses, and the rainy seasons result from mainland Asia and Pacific Ocean air masses (Mehta, 2000;Newman and LeDrew, 2004).

Indonesia contains an array of natural resources in both the terrestrial and aquatic environments. On land, wood, petroleum, tin, natural gas, nickel, timber, coal, gold, and silver are some of the nations most prized resources (Erdmann *et al.*, 2002). In the water, the diversity of coral and fish species exceeds that from any other location on Earth, thereby marking the marine ecosystem as a world center of coral biodiversity. With approximately 60% of Indonesia's population residing near the coast, elements of the coral ecosystems have come to provide building materials, food, and medicines for local people.

Impacts on land aquatic resources are significant, while in the aquatic environment, the increase in phosphate, nitrate, and sediment loading of marine ecosystems, and the incursion of mechanized and technologically sophisticated foreign fishing fleets are rapidly exploiting and damaging reef resources. A study conducted in 2004 indicated 46% of the nation's reefs (50,875 km^2) are at high risk of impact by coastal development, overexploitation and destructive fishing practices, the impact of inland pollution and erosion, and marine pollution (Byrant *et al.*, 1998). As a result of the pressure on reefs, both foreign and local views on reef conditions consider Indonesia's reefs 'in-crisis' and a 'significant management challenge' to achieve sustainable levels of conservation (Byrant *et al.*, 1998).

4.1.2 Ethnicity

Clustered throughout the archipelagic nation of 245 million people (Government estimate for July 2006) there are approximately 300 distinctive ethnic groups, with the majority between the ages of 15 and 64 (Suryadinata, 2002). The majority of people are Javanese (45%), followed by Sudanese (14%), Madurese (7.5), and coastal Malays (7.5%). The nation's religion is primarily Muslim (88%) while the remaining 22% are Protestant, Roman Catholic, Hindu, and Buddhist (Frederick and Worden, 1993). Indonesia officially accepts all five religions listed above; nonetheless, religious tension and conflict exist in places that maintain equal representation of different religious groups.

4.1.3 Political History

On August 17, 1945, Indonesia declared independence and named Sukarno as the country's first president. During the years that followed, Sukarno experimented with democracy. Using his control, primarily through military forces he established 'Guided Democracy', a system that perpetually responded to ever-changing requests. Isolated from global trade, economic prosperity was unachievable. Twenty years later, Major-General Suharto appointed himself as president, following a bloody coup that led to the deaths of up to 500,000 people (Chareonwongsak, 2001). In the years that followed, Suharto enhanced Indonesia's presence in the global trade market, creating rapid economic growth, improving the standard of living, increasing control over social hierarchies, and increasing segregation between city and farm workers (Ricklefs, 2001). In 1997, the Asian economic crisis tipped the scale, following years of religious suppression and diminishing foreign support, and Suharto resigned. Habibie, Abdurraham Wahid, and Megawati Sukarnoputri followed as presidential representatives of Indonesia.

On October 20, 2004, Susilo Bambang Yudhoyono was elected president, the first time in which a member of the Democratic Party was elected. Widely known by the initials SBY, the current president's time in office has been marked by numerous natural disasters. Two months after he assumed office, for example, a tsunami struck the province of Aceh, taking over 200,000 Indonesian lives. Three months later, an aftershock of an earthquake affected residents of Nias Island; and then 9 months later Mount Merapi began erupting. Within the year that followed, earthquakes continued, affecting the residents of Java and the Jakarta capita. With so many isolated events occurring within the first two years of his presidency, Yudhonyono has encouraged the acceleration of power shifts away from Jakarta elites to local government levels to manage these disasters. As a result, the process of decentralization is, in large part, reaching the far boundaries of Indonesia's borders, devolving many key responsibilities once held by Jakarta officials at the national level to regional and municipal level officers. Indirectly, it is hoped that decentralization will stimulate grassroots participation in development, management, and conservation issues, thereby addressing local communities needs and aspirations. However, there still remain many challenges, many of which include lack of managerial experience, democratic mindset, local leadership, and on-going corruption at all societal levels (NRM member, June 2004, personal communication).

4.1.4 National Marine Protected Area Management

In 1986, during Suharto's reign, Indonesia formally ratified the United Nations Convention on the Law of the Sea, which provides legal controls for the management of marine resources and the control of pollution. By signing the Convention, Indonesia agreed to uphold practices and policies that sought to balance development and conservation activities particularly in coastal areas (Erdmann *et al.*, 2004). This action prompted involvement from Indonesia's Ministry of Forestry to set up nature conservation reserves and parks. Working with the IUCN and WWF to develop marine conservation programmes and policies, Suharto's government declared 10 million hectares of marine and coastal areas by the end of 1994, and proposed protection for 30 million hectares by the year 2000. Beginning in the late 1980s, Indonesia's first national marine park was under development. Following two decades of continually shifting designations, the Park was formally established and with assistance from USAID's Natural Resource Management Project a 25-year management plan was created, thereby satisfying the legal requirement for the establishment of a park office (Erdmann *et al.*, 2004).

In 1991, Bunaken National Park was formally recognized and represented Indonesian efforts to protect and conserve a region of, arguably, the highest marine biodiversity in national waters. Covering an area of 89,056 hectares of both land and sea and occupied by approximately 30,000 people, Bunaken National Park came to symbolize Indonesia's commitment to conservation as well as an ability to achieve national and international directives. Today, MPA Global, a database of the world's marine protected areas funded by Sea Around Us, WWF, UNEP, WCMC, and IUCN, lists 19 marine national parks within Indonesia, encompassing an area of approximately 58,851.5 km^2. By area, Bunaken National Park accounts for 1.3% of this total.

4.2 BUNAKEN NATIONAL PARK

4.2.1 Geography

Bunaken National Park (BNP) encompasses some of the richest marine biodiversity in the world (Mehta, 2000). Located in the Coral Triangle – the area of richest marine biodiversity – the 89,056-hectare park provides habitat to more than 1,000 species of coral reef fish and 400 species of hard coral representing 63 genera and 15 families (Mehta, 2000). Each island within the park is surrounded by a fringing reef beyond which the seafloor drops to over 2000 metres, providing channels for migrating pelagic species, including sharks and whales (Mehta, 2000). Portions of the park, connected to the mainland, host over 30 mangrove species, which provide protection for dugongs, turtles, and giant clams (Mehta, 2000).

According to the Ministry of Forestry, the park is divided into two equally sized sections. The northern part of the Park includes the major islands of Bunaken, Manado Tua, Mantehage, Nain and Siladen, and the coastline region to the north of Manado. The southern part runs adjacent to the coastline south of Manado, and safeguards extensive mangrove and sea grass habitats (Figure 4.2).

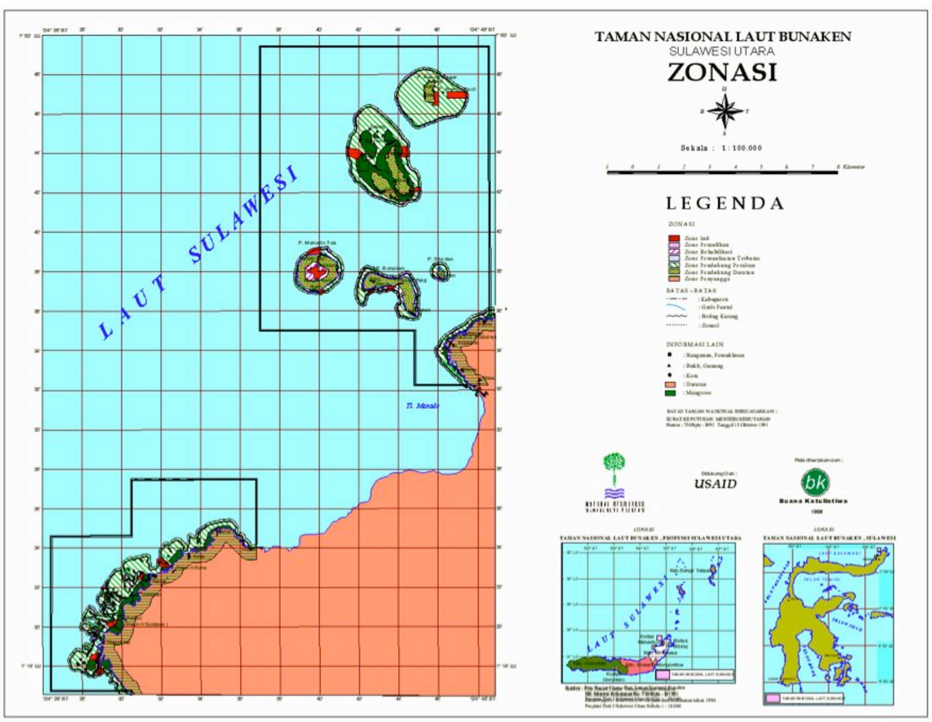

Figure 4.2. Location of the northern and southern parts of Bunaken National Park. Source: NRM-USAID Manado.

4.2.2 Stakeholder Groups

Bunaken National Park is home to more than 30,000 villagers living in twenty-two villages or directly adjacent to the Park. Many villagers are dependent on Park resources for their livelihoods as well as the major protein source in their diet. While villagers agree on Bunaken National Park's conservation value at the local level, they often compete for a range of the Park's resources, including dive sites, fish and marine resources, and mangroves and tourism development. As a result, stakeholder groups are defined by resource use and form two main categories: fishers and dive operators. Over 20 dive operators service approximately 20,000 visitors to the Park on an annual basis. In terms of contribution to the North Sulawesi economy, both groups contribute almost equally, with fisheries contributing approximately $3.8 million annually and tourism revenue generating $4.4 million per year (DeVantier and Turak, 2004).

4.2.3 Cornerstone of Management Efforts

At the cornerstone of Bunaken National Park lies the Bunaken National Park Management Board and the zonation plan.

4.2.3.1 Bunaken National Park Management Board

In the mid-1990s, the two primary user groups of the Park consolidated into two independent constituency-based partnerships that became formally recognized as the North Sulawesi Watersports Association and the Bunaken Concerned Citizen's Forum. Degradation of reef resources and lack of management effort at all government levels fueled the formation of these groups. Shortly afterwards, the national government created the Bunaken National Park technical management unit, a team of people situated both in a central office and at ranger posts throughout the Park with the express purpose of Park management. However, the Asian financial crisis provided staff with insufficient funds to operate outside of their office buildings, thereby considerably limiting their involvement in local management. Recognizing that the lack of finances and human resources to manage Bunaken National Park, the government agreed to allow the Park to experiment with collaborative management and alternative financing systems. In May 2000, a meeting was called and brought together various government, NGO, private sector and academic stakeholders to develop a collaborative, multi-stakeholder body for BNP. Through a series of workshops, the shape of a co-management board evolved and, with assistance from foreign and local NGOs, the Bunaken National Park Advisory Board was created. It was agreed that the Board would consist of 15 seats, eight assigned to non-governmental representatives and seven assigned to government representatives (Erdmann *et al.*, 2002) (Table 4.1).

Table 4.1. Representatives on the Bunaken National Park Management Advisory Board.

Non-Government Representative	Government Representative
North Sulawesi Watersports Association (Vice-Chair)	North Sulawesi Vice Governor (Chair)
Chairman of Bunaken Concerned Citizen's Forum	Bunaken National Park Office
Secretary of Bunaken Concerned Citizen's Forum	Provincial Environmental Impact Control Department
Head of Island Section, Bunaken Concerned Citizen's Forum	Environmental Impact Control Department (District)
Head of Northern Section, Bunaken Concerned Citizen's Forum	Manado City Environmental Department
Head of Southern Section, Bunaken Concerned Citizen's Forum	Provincial Tourism Department
Faculty of Fisheries and Marine Science, Universitas Sam Ratulangi	Provincial Department of Fisheries and Marine Affairs
Indonesian Forum for The Environment (WALHI)	

According to the BNP Management Plan (1996), the purpose of the Board is to:

1. Instill a sense of pride and ownership by local stakeholders in the conservation of BNP;
2. Coordinate the policies of the various government agencies with decision-making authorities within the Park; and
3. Support the Bunaken National Park Office in formulating and funding conservation programs for the Park.

On December 16, 2000, the Bunaken National Park Management Advisory Board was officially sworn-in by the Ministry of Forestry in the city of Manado and a new logo with a pair of hands supporting the Bunaken National Park logo was created to illustrate that the Board was in place to support the Park Office, not to compete or replace it (Erdmann *et al.*, 2004).

4.2.3.2 Zonation Plan

Six years earlier, efforts began to develop a zonation plan for each section of Bunaken National Park. The zonation plan was defined as a system of recognized permissible and non-permissible activities for various zones and each zone would contain clearly demarcated boundaries. At the outset of these efforts, the Ministry of Forestry clearly indicated that the plan should focus on minimizing conflict between the two main user-groups in the Park (NRM member, May 2004, personal communication). Thus, the zonation plan was expected to reflect a compromise between stakeholders, rather than a reflection of resource types and resource quality. The BNP zonation was to be built upon socioeconomic data, opinions and livelihood strategies (Erdmann *et al*, 2004) and aligned with the Biodiversity Conservation Act, which requires three main zone types: (1) core zone, (2) tourism use zone, and, (3) and community use zone. According to the Act, the core zone must make up 20% of the total area and must represent a signature area or region where the level of biodiversity is high both on land and in the water (Bohnsack *et al.*, 2002). In addition, the core zone must extend from water to the land and include dominant coastal features: coral, seagrass, sand and mangrove. The core zone must be available to researchers only, thereby reducing the amount of activity in an area of high biodiversity. The tourism use zone must be recognized as an area suitable for tourists and researchers, while the community use zone must be available to tourists, researchers, and fishers. Therefore, the zones are indirectly ranked by activity level; from the lowest level activity occurring in the core zone and the highest level of activity in the community use zone.

In 2001, USAID's Natural Resource Management (NRM) Program was asked by the Ministry of Forestry to provide technical assistance in the development of the zonation plan and to act as a facilitator between community villagers and dive operators, as the development of the plan was expected to be highly participatory (Erdmann *et al.*, 2004). NRM succeeded and with input from local scientists, dive operators, fishers, and community leaders the first zonation plan was created (Erdmann *et al.*, 2004). Local scientists, who had been asked to lead the placement of the core zones, concluded that the necessary scientific data to demarcate these areas were unavailable. Therefore, it was suggested that fishers and dive operators use their local knowledge of the area and identify the most appropriate location for not only the tourism use and community use zones, but also for the core zones. In addition, scientists noted that these stakeholders would be primarily responsible for managing each zone, so stakeholders should provide input to zone placement decisions (UNSRAT member, personal communication, June 2004).

Initially, eight different zone types with titles and rules for each were selected. Out on the water, however, distinguishing between each zone was challenging, as water buoys were unavailable and land markers had been ambiguously identified as separation points. In the water, many broad geomorphological areas were delineated into smaller regions to isolate sensitive areas that were at risk of severe deterioration. Unclear demarcation of zone boundaries out on the water made user compliance with the plan difficult and frustrated stakeholder groups. In addition, it was clear that the initial zonation plan represented the interests and ideas of a select group of individuals and not the primary values of all communities. As a result, the plan was not accepted, exemplified by the lack of compliance with zone regulations in various areas. In 2000, efforts to develop a second plan began and NRM focused on employing a full participatory process in which the majority of members from every socio-economic group would be consulted (Edmunds and Wollenberg, 2001). Meetings were held in all villages in an attempt to better socialize the process and to gather a wider range of opinions and local knowledge. Fishers and community members were asked to identify the most appropriate location of the three dominant zones, and the rules for compliance in each zone were discussed. Efforts were also made to include all groups socio-economic groups (Edmunds and Wollenberg, 2001).

Determination of the location of each zone was based primarily on stakeholder input and their experiences with specific sites around the islands (PHKA, 2002). The community use zone, for example, represents an area in which fishing is permissible as well as collection of mollusks and shellfish from the coastal area. The tourism use and core zones are meant to represent 'no-take' zones where fishing is not permitted. These areas protect spawning aggregation sites for juvenile fish and endangered species, such as the grouper. The idea is that years of protected spawning in these areas will lead to spillover outside of these two zones into areas where fishing is permissible, thus enhancing long-term fisheries benefits (WWF member, personal communication, June 2004). The tourism use zone is also seen as a means of protecting the high biodiversity consistent at numerous dive sites. Identifying the location of dive sites and fishing areas, socializing the benefits of no-take zones, and considering the ability of the community to manage the resources resulted in the existing placement of the zones (Usher and Merrill, 2000).

Following 16 months of numerous town hall, focus group, and all-inclusive meetings, consensus was reached among the village stakeholders. For the dive operators, meetings were held to achieve similar objectives: to gather input and impressions from people who would be directly affected by the zonation plan. The final zonation plans for each island were displayed on aluminum billboards throughout villages and calendars were created to communicate both the location of the zones and the regulations. Upon posting of the zonation plan, enforcement came into effect.

4.3 RESEARCH SITE: BUNAKEN ISLAND

4.3.1 Geography

Bunaken Island lies off the Northeast point of Sulawesi, Indonesia near the city of Manado. Approximately 3 km from the mainland, Bunaken is volcanic in origin. The eastern part of the island is low-lying, remaining at approximately 1-2 metres above sea level, whereas the western part of Bunaken is dominated by a hilly land system of coral limestone and volcanic soils where the topography reaches 71 metres. There is a flat plateau in the central portion of the island that reaches approximately 50 metres (Figure 4.3). At the shoreline, red mangrove trees dominate except in areas where dive operations have been built. Since the inception of the management plan, mangrove trees were recognized as unique to the Park and mangrove removal was no longer permitted. Extending outwards from the shoreline, the island is surrounded by well-defined tropical coastlines, which includes a tidal flat, reef crest, reef slope, and reef wall. In some areas, the tidal flat extends up to 0.5 km from the shoreline. At the reef wall, the water depth drops down to the continental slope at 1840 metres. In the waters surrounding Bunaken Island, there are a minimum of 58 general and sub-genera of corals and approximately 2,000 species of fish (Figure 4.4). Rare or endangered species that frequent the coastal waters include dugongs, whales, dolphins, turtles, tuna, and sharks (Mehta, 2000).

Figure 4.3. Photos taken in Bunaken Village and along the trail that extends from the southeast corner of Bunaken Island to the west coast.

Figure 4.4. Marine resources beneath the waters of Bunaken Island (< 30 metres deep).

4.3.2 Local People

According to a consensus that was conducted in 1999, there are three villages on the island of Bunaken: Alung Banua (population: 807), Tanjung Parigi (population: 610), and Bunaken (population: 2000) (Figure 4.6) (BCCF member, June 2002, personal communication). The people living in the villages are descendents of fishers who used Bunaken Island as a stopover location before heading out to sea. Historically, Bunaken Island was used as resting and resource gathering location. People have been living on the island for approximately five generations. The people were originally farmers and fishers and these occupations continue to dominate today along side dive operators that began to flourish in 1990. Those who are farmers are also fishers and are locally known as the KKK, which means fishers when it’s dry and farmers when it’s wet. The fishers/farmers tailor the timing of their occupation to the weather, primarily to the strength of the westerly winds. When the winds are strong, during the wet season, the men stay on the island as the winds are too strong to manage the wooden fishing boats. When the winds are from the east, they are characteristically weak, and fishing activities dominate. Three types of fishers operate around Bunaken Island: the hook-and line fishers, the purse seining fishers, and the deep-sea fishers. Dive operators are mainly foreigners from England, France, and Canada. The operators are half-owners of the dive operations, as it is mandated by Indonesian law that foreign operators may only own up to 50% of an Indonesian company (Figure 4.5). The majority of the Bunaken Island’s local population is Christian, except in the village of Bunaken where several groups are Islamic. A mosque, for example, was built in 2003 in Bunaken Village to accommodate the increasing numbers of Islamic worshippers. The children on Bunaken Island attend elementary school in their respective villages and when they are old enough, they attend junior high-school in Bunaken Village.

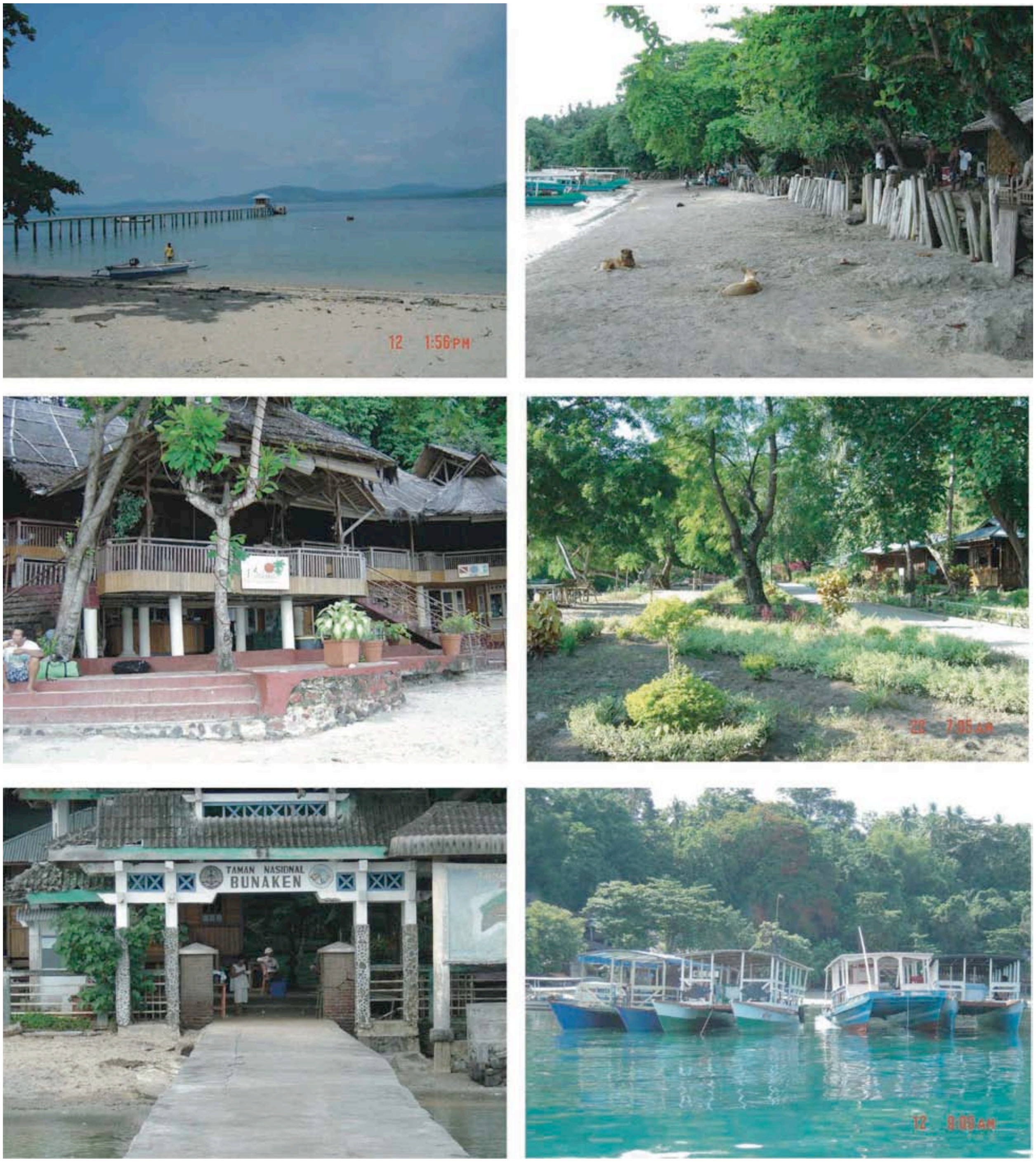

Figure 4.5. Dive operations located on both the northern and eastern costs of Bunaken Island.

4.3.3 Zonation Plan

Bunaken Island was the first island in Bunaken National Park to be assigned a zonation system. The system includes three primary zones: core conservation zone, tourism use zone, and village use zone (Figure 4.6).

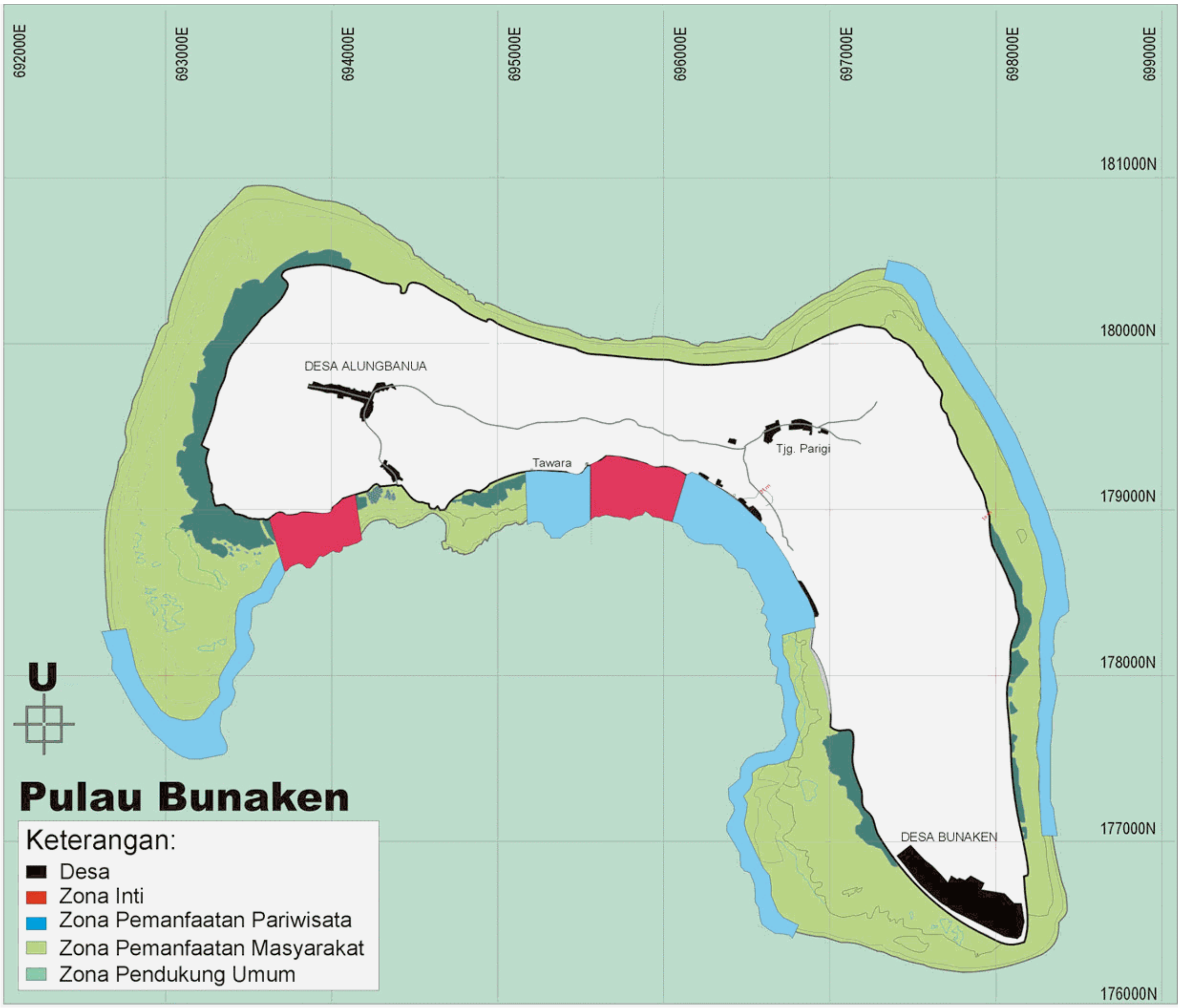

Figure 4.6. Final zonation plan for Bunaken Island (Translation: Pulau Bunaken = Bunaken Island; Keterangan = Legend; Desa = Village; Zona Inti = Core Zone; Zona Pemanfaatan Pariwisata = Tourism Use Zone; Zona Pemanfaatan Masyarakat = Village Use Zone; Zona Pendukung Umum = Buffer Zone). (Source: PHKA, 2002; Erdmann *et al.*, 2004).

4.3.4 Non-Zonation Management Efforts

Beyond the zonation plan, coral reef management activities include the use of ecoreefs in shallow water coastal areas that have experienced considerable blast fishing to encourage coral reef growth. The coral reef crest environment nearby Alung Banoa Village and Fukui dive site now hosts over 60 ecoreefs that were provided by Seacology and implemented by NRM III personnel and local fishers and dive operators (Figure 4.7). Ecoreefs are ceramic star-shaped structures that are designed to encourage coral growth in areas that are absent of the underlying coral framework on which larvae attach. Unlike alternative coral reef growth strategies, ecoreefs do not require a catalyst such as an electrical current to encourage growth.

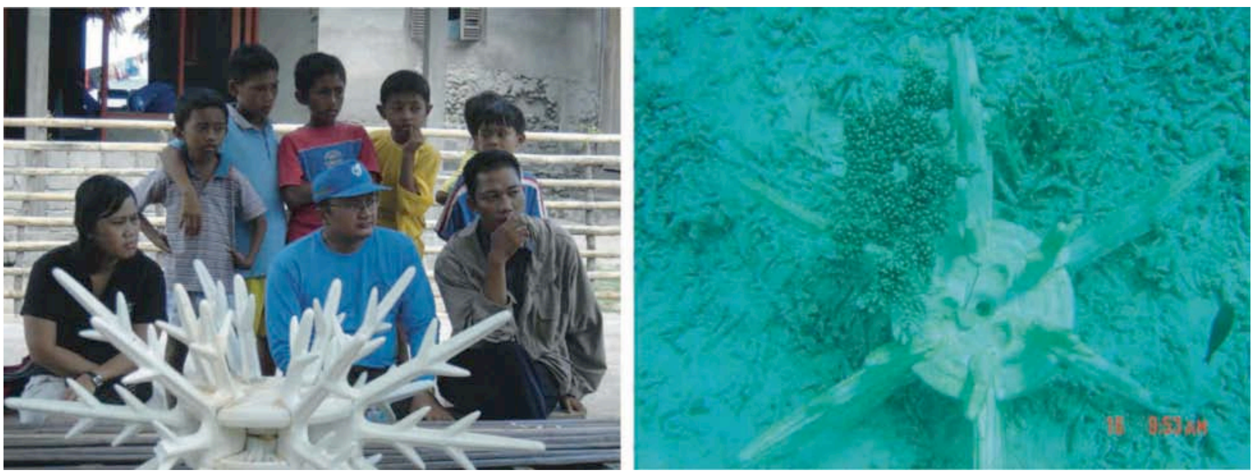

Figure 4.7. Examples of an ecoreef both above and below water.

A second coral reef management activity that is increasingly applied by dive operators is coral reef monitoring. Several dive operations have tailored their Open Water, Rescue Diver, Dive Master, and Dive Instructor courses to include a monitoring program that requires the candidate to make quantitative observations of coral health during each dive. In addition, the candidate must take notes on specific fish species such as groupers, sharks, and other species that are of value to the dive operation. Species that are of value are those visitors wish to see while diving.

Non-coral reef management activities include Spawning Aggregation Site (SPAG) monitoring. A SPAG site is defined as a location where grouper species are regularly found during their spawning period (Figure 4.8), and monitoring involves repeated counts of grouper species at these sites during the spawning period. Fishers and patrols have been trained to conduct counts of groupers during this period and submit the information to local and foreign NGOs. The purpose is to encourage the local community to build a database on grouper spawning activity that will be combined with fishing effort data to estimate the degree of protection required at these sites. Other activities include building huts for local women who sell necklaces, t-shirts, and decorative ornaments at the main dock, developing a trust fund for students who can apply for scholarships to attend UNSRAT, and investigating the effectiveness of patrol activity (Figure 4.9). Management activities are initiated by both NRM III and the Bunaken National Park Management Board.

Figure 4.8. SPAGS training on Bunaken Island. Lead by WWF coordinator and attended by local dive operator owners and staff and island patrols.

Figure 4.9. Photos of local development projects including building huts for women to sell necklaces to visitors, information boards, beach cleanup projects, manta tow surveys, and island patrol.

4.3.5 Bunaken Island Today

There is little doubt that the existing zonation plan for Bunaken Island was created to appease the two dominant stakeholder group activities. Essentially, the zonation plan reflects the location of the dive operation and fishing activities. Moreover, the profound impact of increasing tourists on the local communities has brought about change. Increasing tourist dollars have motivated individuals to place their short-term gain over long-term communal objectives. This, combined with national, democratic elections in Indonesia, has led to the changing perspectives on the usefulness of the Bunaken zonation plan. The 2002 Bali bombing occurred on the island of Bali, killing 202 people and injuring more than 250. The majority of people affected during the bombing were tourists. As a result, tourism to Indonesia dropped significantly. The following year, for example, Bunaken Island foreign visitor numbers dropped to 3,000 with the majority arriving from countries in Europe. By 2004, tourist number increased to (DeVantier and Turak, 2004) reaching their highest values recorded for Bunaken Island. With increasing numbers, dive operators have been able to increase the number of boats and the type of boats they use for diving expeditions. Consequently, the waters surrounding Bunaken Island have higher traffic levels than observed in the last 10 years (NSWA member, August 2001, personal communication). The social impacts from increasing tourist numbers have been far reaching. For example, conflict has arisen (1) within communities where an increasing number of members work for local dive groups, which is not considered a significant contribution to the community, (2) between communities where contributions from each community are not equal, and (3) between Bunaken Island and mainland peoples where Bunaken Island community members are concerned with the increasing amount of mainland garbage claiming the shorelines of Bunaken. Conflict also arose during local election campaigns. Several municipal candidates choose to speak from a platform that targets the deficiencies of the Bunaken Island zonation plan. A consequential action was that fishermen, angered by the deficiencies, physically damaged the reef crest in areas designated for dive operations. This action created significant polarization within the community and influenced future decisions over how to protect marine resources.

CHAPTER FIVE:
DEVELOPMENT OF A CORAL REEF HABITAT MAP FOR BUNAKEN ISLAND, INDONESIA

SUMMARY

This is the first stage in a strategy that guides the use of remotely-sensed information in coral reef management for Bunaken Island, Indonesia. In this chapter, IKONOS satellite imagery from 2001 and 2004 is used to create two habitat maps of the coral reef ecosystem. Ground observation points are collected during both years and used to develop both common and site-specific habitat classes. The image data are corrected using atmospheric and water column correction methods, and classified using a supervised classification measure. Results include two habitat maps and associated producer, user, and overall accuracy values. The habitat maps are then used to conduct a change detection analysis. Changes in the spatial location and extent of coral and seagrass are assessed. Both habitat maps and the change detection analysis maps are used in subsequent stages of the strategy.

5.1 INTRODUCTION

IKONOS was launched in 1999 as a commercial earth observation satellite and was the first satellite-borne sensor to collect publicly available multispectral, 4-metre resolution image data: specifications ideal for viewing coral reef ecosystems in shallow, low-sediment waters. Almost immediately, IKONOS became the sensor of choice for mapping the spatial location and distribution of coral reef habitats, and over time, IKONOS imagery was used for mapping changes in habitats. Studies in the scientific literature began to appear in early 2002, when Mumby and Edwards (2002) evaluated and then compared the accuracy and cost of using IKONOS imagery, CASI, and Landsat TM to map coral reef habitats. Results suggested that IKONOS imagery provides higher habitat mapping accuracy when geomorphological zones (accuracy 75%) were mapped. The authors concluded that IKONOS imagery was ideal for mapping coral reefs if the objective was to identify habitat patches such as coral, seagrass, sand, to map a relatively small area (< 500 km^2), and to identify changes in small-scale (<10 m) habitat dynamics. Studies that followed supported this conclusion (Maeder *et al.*, 2002; Capolsini *et al.*, 2003; Hochberg and Atkinson, 2003), and noted that the high-resolution images provided an opportunity to characterize inter-reef structural differences, and to map intra-reef habitat diversity zones, to assess bathymetric variations in the seascape, and to map beta-diversity (diversity between groups) (Mumby 2004; Harborne *et al.* 2006), options not previously available by medium-resolution sensors such as SPOT and Landsat (Ahmad and Neil, 1994; Hochberg and Atkinson, 2000; Andréfouët, *et al.*, 2001; Andréfouët and Payri, 2001b; Pukis *et al.*, 2002; Capolsini *et al.*, 2003).

5.1.1 Habitat Mapping Using IKONOS Imagery

Numerous coral reef remote sensing studies have provided insight about the number and types of habitats that can be expected from IKONOS image data. In 2002, Mumby and Edwards differentiated habitats into a 'moderate to simple' classification scheme of five to nine habitat types at overall accuracy levels of 64-75%. Habitat types included medium soft coral density and rubble (first class), bare substratum and low soft coral density (second class), bare substratum and medium soft coral density (third class), and numerous additional classes. Capolsini *et al.* (2003) mapped reef habitats in Tahiti into 7-13 classes with an overall accuracy of 66-86%. Maeder *et al.* (2002) mapped habitat types that surround Roatan Island, Honduras into five different classes with an overall accuracy of 85%. It is increasingly evident that the results between studies are consistently similar, in terms of the number of habitat types mapped, the types of habitats, and the overall accuracy. Variation in the methods used to arrive at the final habitat classification scheme are found.

Initially, habitat types were examined on the ground, separated into biological or geomorphological categories, sampled using hand-held spectral radiometers, then spectrally matched with spectral signatures in the imagery. In the last 5 years, methods that incorporate fewer field observations are being explored, primarily to reduce the time and effort involved in field data collection. For example, Mishra *et al.* (2005) employed a 'sensor-down' approach that involved first acquiring IKONOS image data, next applying atmospheric and water column corrections, and then applying several algorithms to calculate water depth for each pixel using a polynomial model, and to retrieve an estimate of the bottom reflectance using a radiative transfer approach. The final data set was used to classify habitat types, and ground observations were used to assess the accuracy of the classification. The habitat map included dense seagrass, mixed (seagrass/sand/algae), mixed (coral/sand), coral, and deep water.

Purkis *et al.* (2006) explored the use of a texture-based classification method that detects spatial patterning as a function of spectral variation in an image scene. The Moran's I spatial autocorrelation metric was explored and following application returned different values for areas characterized by patches of Acropora cervicornis and patches of Montastrea annularis. The authors concluded that the differences in physical characteristics of A. cervicornis and M. annularis at large spatial scales (tens of metres) created sufficient pattern difference for detection with a moving window. As a result, the final image classification included two habitat types.

5.1.2 Defining Habitat Types in Coral Reef Ecosystems

New habitat classification methods continue to evolve and produce habitat maps of varying habitat types and numbers. As a result, a consistent, standard habitat classification technique has not bee presented. However, there are several procedures that are consistently used in most scientific studies: image and field data collection, image processing (atmospheric/water column correction, dark pixel subtraction, masking, supervised classification).

When considering a 'bottom-up' approach, ground observation points are collected and used to drive a supervised classification, habitat type selection methods can be placed along a gradient between ad hoc selected habitats and habitats that have been identified using a multivariate statistics operator. Ad hoc selection typically involves identification of common habitat types such as coral, seagrass, and sand, and site-specific habitat types that are unique to the area. Multivariate statistics operators include the Bray-Curtis (Bray and Curtis, 1957) operator that categorizes habitats based on a similarity index developed by the operator. These methods and those that include a mixture of ad hoc and multivariate analysis host a number of advantages and disadvantages, and although an ad hoc method is less scientifically sound and therefore, less desirable, it is commonly used because of limitations in the availability of field data and computational support (Mumby and Harborne, 1999). Currently, one of the greatest challenges on the ground is to acquire precise GPS coordinates over different habitat types. Existing GPS units provide an accuracy of 2-3 metres, which is insufficient. Within a 2-3 metre radius, habitat types may include a full mixture of coral, seagrass, and sand, thereby confounding data collection and image classification. Fortunately, there are several methods for overcoming this problem and include the use of a differential-GPS unit to improve positional accuracy, selection of geomorphological classes that have a large spatial extent, and/or use of the imagery in the field to delineate locations of habitat types.

5.1.3 Recent Alternatives to Habitat Classification

Alternative habitat validation field methods are not the only approach available to define habitat classes within an IKONOS image scene. Goodman and Ustin (2007) presented a refinement of an algorithm to retrieve bottom albedo and water depth using AVIRIS hyperspectral data over Kaneohe Bay, Hawai'i. This technique produced promising results for estimating the relative cover of coral, algae, and sand within each pixel. Goodman and Ustin assigned, like many other authors, coral, seagrass, and sand as dominate substrate types in the shallow-water environment and used this to guide the classification. Although the technique requires the operator to collect data on the diffuse attenuation coefficient at the site of interest, it provides an alternative to collecting numerous ground observation points and to defining all substrate types or 'endmembers' within an image.

Using a variety of both field and image data for Heron Reef, Australia, Joyce (2004) developed a coral cover index method to produce a map of live coral cover using high spatial and spectral resolution data. The method provides a means of estimating absolute live coral cover throughout a scene; a method that is applicable in other reef systems and provides a useful indicator of coral reef health. Using CASI-2 hyperspectral image data at 1m spatial resolution, and surveys of substrate variability and proportion of live coral coverage through collection of ground observation points and transects, correlations were made between ground and image data to select the best transformation of data. Next, extensive modeling and comprehensive testing of the relationship between spectral reflectance and live coral cover was conducted, and followed with further testing of band ratios and spectral derivates involving simulations with Hydrolight 4.1. The greatest benefit of this research is that it provides a reproducible and systematic approach to habitat classification.

To-date many coral reef remote sensing studies have used habitat classification methods that suit the operator's knowledge of image processing techniques, the availability of field data, the ability to access the research site, and that address the objectives of the study. As a result, habitat types vary from one study to the next, thereby creating uncertainty about the 'best approach' for mapping coral reef ecosystems. According to Green *et al.* (2000), however, there is "no absolutely correct method of categorizing (classifying) ecological habitats so the choice of methods depends on the objective(s) of the study". Generally, the classification should reflect the dominant habitats in the study area as accurately as possible, and the classes themselves should be easily interpreted and clearly representative of the substrate (Green *et al.*, 2000).

In this chapter, the approach by Green *et al.* (2000) is adopted, which involves using the operators experience and the availability of field and image data to develop a habitat map of the coral reef ecosystem surrounding Bunaken Island, Indonesia. Ground observation points are used to define the type of common and specific habitat types, while an IKONOS satellite image is used to identify the spatial location and distribution of habitats, as well as conduct a supervised classification. The objective of this study is to map, with the greatest level of precision under the parameters listed above, habitat types within the coral reef environment.

5.2 STUDY AREA

This study focuses on Bunaken Island, which lies within the boundaries of Bunaken National Park (N 1^{o} 35' - 1^{o} 49'; E 124^{o} 39' - 124^{o} 35'), North Sulawesi, Indonesia. Although the IKONOS imagery also includes the neighbouring islands of Manado Tua and Siladen, the field data for these two sites is insufficient to create an accurate habitat map; therefore they are not included in this or subsequent research presented in this dissertation. A complete description of the physical environment is provided in Chapter Four.

5.3 METHODS AND MATERIALS

5.3.1 Field Data Collection

Field data collection was carried out from May to August in 2001 and 2004; two independent data collection approaches were conducted. In 2001, approximately 725 ground observation points were collected in each geomorphological zone in the coastal waters surrounding Bunaken

Island (Figure 5.1). In 2004, data were collected for these same locations. For each ground observation point, a Magellan GPS was used to collect latitude and longitude coordinates, depth was recorded with hand-held sonar or depth gauge, and the substratum was photographed with a Sony D-10 camera in an underwater housing and notes were taken (see Figures 5.3-5.7 for examples of substrate types). Ground observation points were acquired by walking throughout the reef flat when the tide was low and by snorkeling or by boat over the reef crest and reef slope when the tide was high. Measurements from a local outrigger were made on days when winds were calm. Photos of the substrate, GPS measurements, and notes were also were taken along 12 transects, at 1/2 metre intervals, from the shore to the reef crest (Figure 5.1). The location of transects was selected with input from local scientists at Sam Ratulungi University.

GPS measurements were consistently recorded during the field period at ground observation points and along transects. The precision of the GPS measurements was estimated to be at +/- 2-3 metres, based on repeated measurements taken at a fixed point. To complement the GPS data, the panchromatic IKONOS image was printed, and the location of ground observation points were marked on the image for future reference. This process assisted in geolocation of the ground observation points, was crucial when data were collected near boundaries between substrate types, and provided considerable confidence, in locating habitat types, when conducting the supervised classification procedure.

Figure 5.1. Location of ground observation points and transects.

5.3.2 Field Data Processing

All data collected for 2001 and 2004 were entered into a spreadsheet in Microsoft Excel and referenced by ground observation point number. For each ground observation point, latitude/longitude coordinates, depth, water quality, water surface roughness, and date were indicated. The type of habitat was noted in terms of species/genus where possible, biology (coral/seagrass/sand), structure (branching, plate, boulder), health (living/dead/algae-covered, sediment-covered), and geomorphologic zone. Digital photos were labeled by ground observation point number and inserted into the spreadsheet. Next, the habitat data were used to construct a hierarchy of both common habitats, defined as the dominant and recurring habitat types found throughout most coral reef ecosystems, and site-specific habitats, defined as habitat types that are unique to an area and may or may not recur throughout the ecosystem (Figure 5.2).

Habitat data are defined as a collection of subsurface coral reef features that have relatively consistent biological and structural characteristics. Habitat data were classified into different types, and are defined as follows: coral is defined as live coral; seagrass is defined as live seagrass; sand includes an area that contains more than 75% sand; silt includes an areas that contains more than 75% silt; rubble refers to fragmented coral pieces; lagoon is defined as an enclosed region of 10-15m deep; boulders include large rocks that do not host living or dead coral; silt covered coral refers to corals that have maintained their structural integrity but are covered (> 50%) in organic or inorganic sediment.

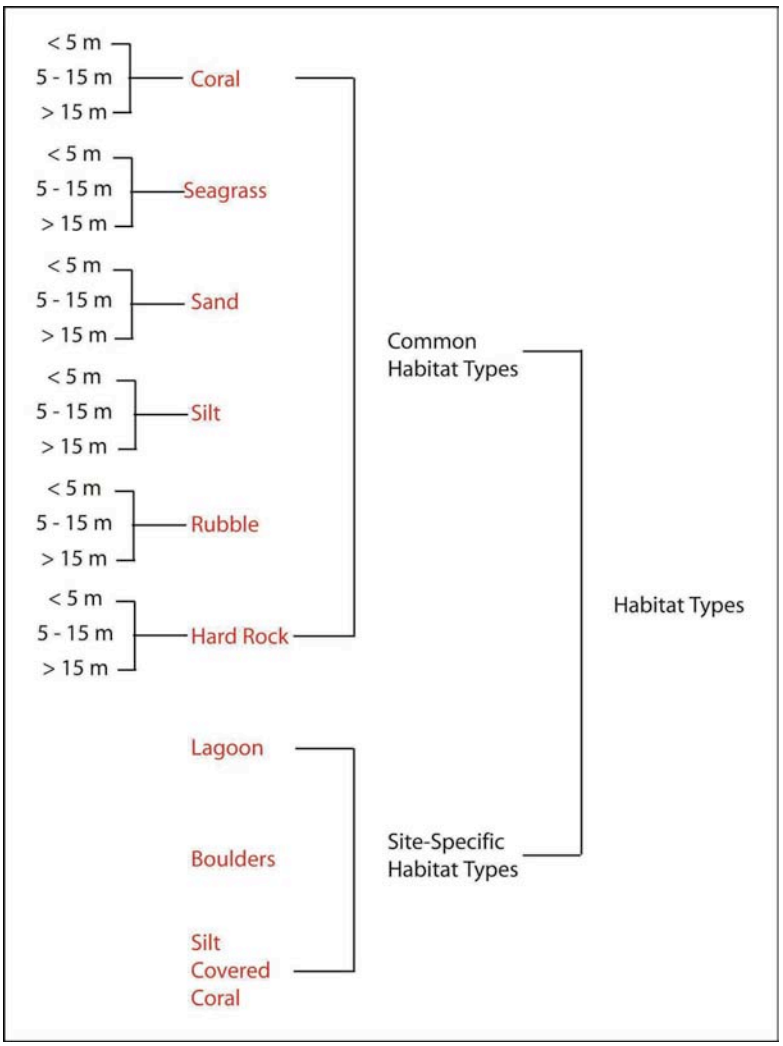

Figure 5.2. Common and site specific habitat types identified in the coral reef ecosystem.

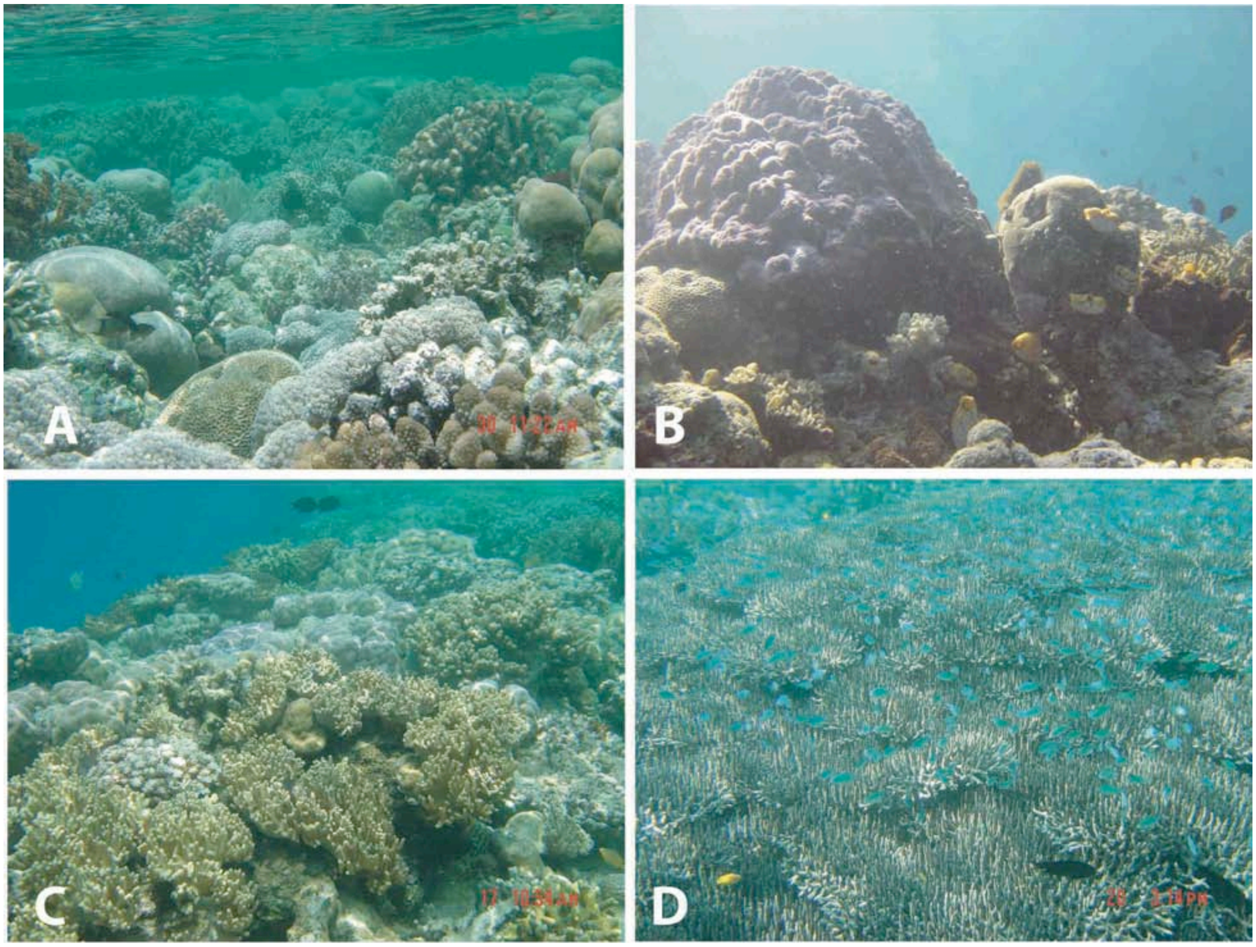

Figure 5.3 Examples of coral habitats at different depths. A: Mix of hard and soft coral species at <5 m; B: Porites and Acropora species at 5-15 m; C: Mix of hard and soft coral speices at >15 m; D: Acroporal species t < 15 m.

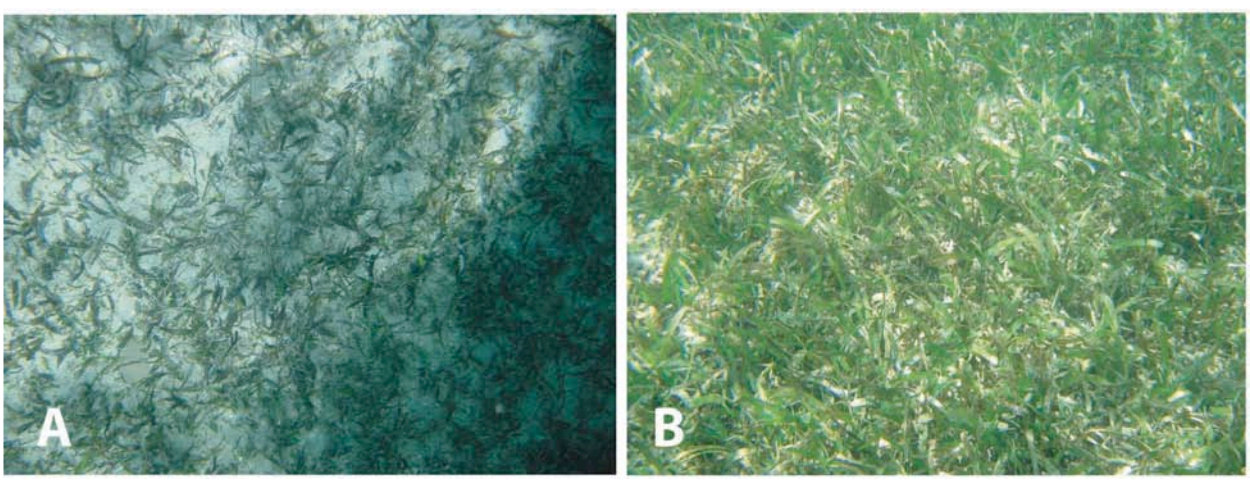

Figure 5.4. Examples of seagrass habitats at different depths. A: Halodule uninervis, Cymodocea serrulata, and Cymodocea rotundata at < 10 m; B: Thalassia hemprichii at < 5 m.

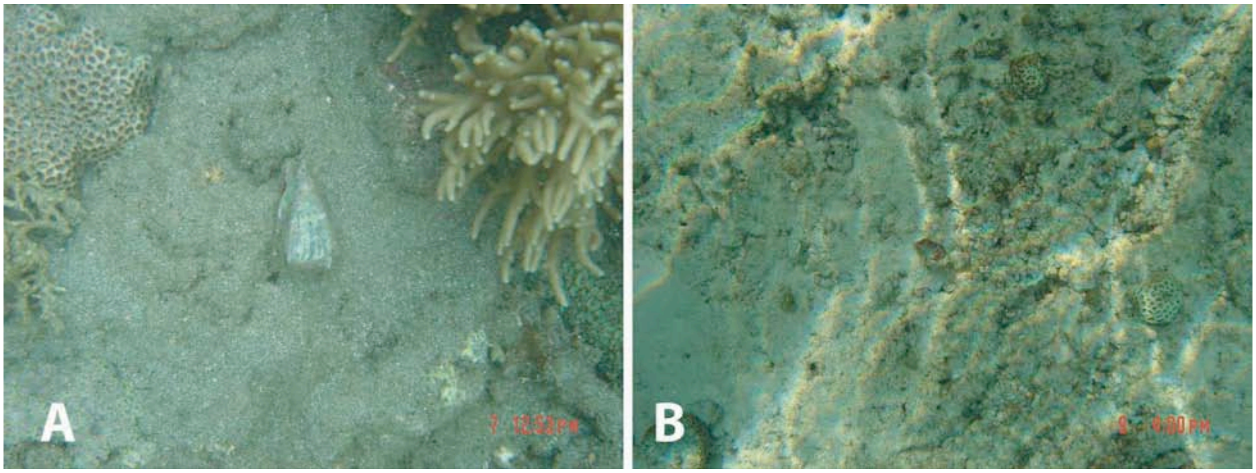

Figure 5.5. Examples of silt. A: Silt at > 10 m; B: Silt at < 5 m.

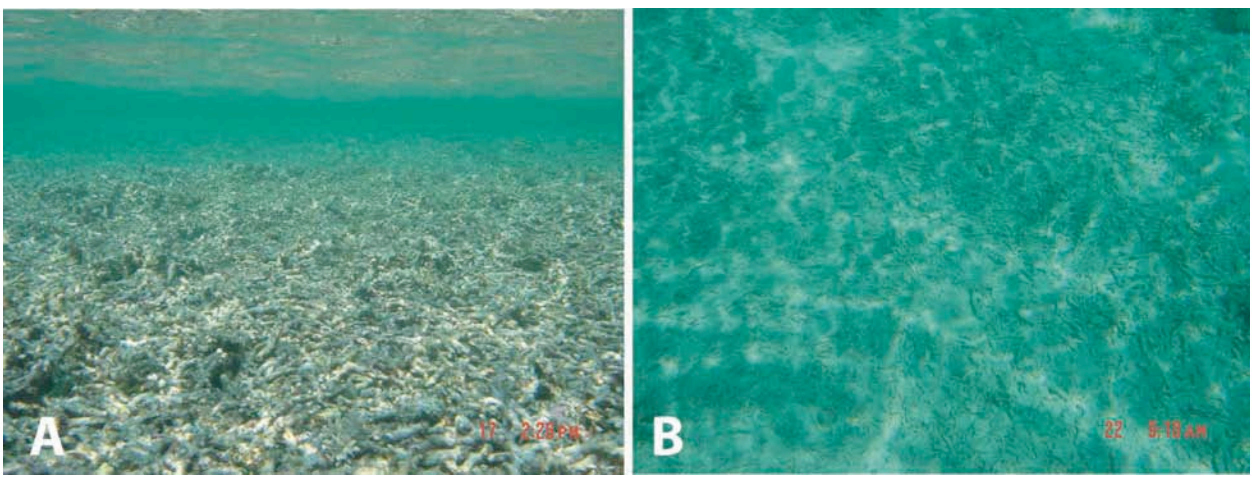

Figure 5.6. Examples of rubble. A: Rubble at <5 m; B: Rubble at 5-15 m.

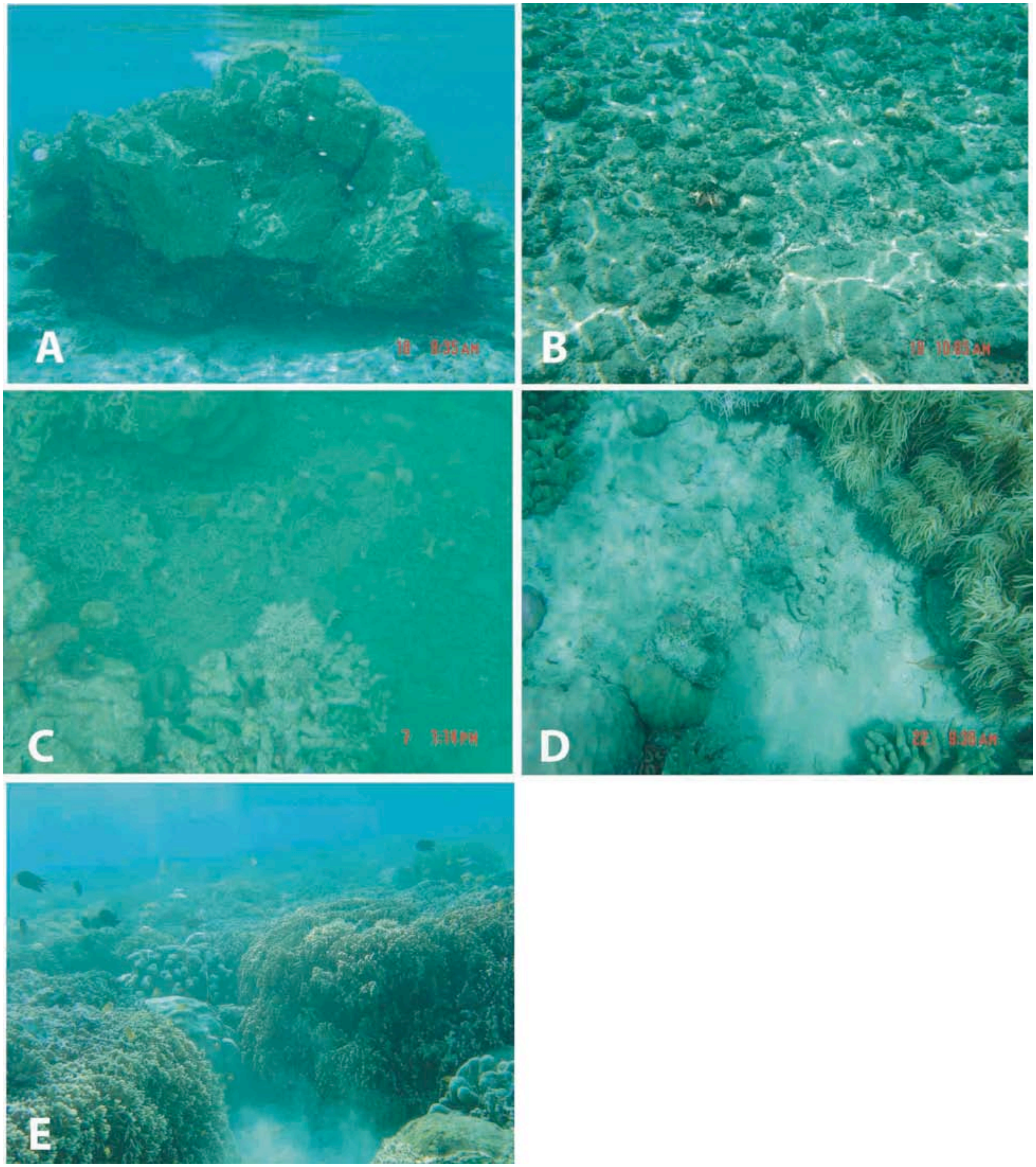

Figure 5.7. Typical examples of additional common and site-specific substrates identified within the study site. A: Boulder; B: Hard Rock; C: Silt Covered Coral; D: Sand; E: Lagoon (appears as coral, however, the coral is >15m deep and is not visible from the surface).

5.3.3 IKONOS Image Acquisition

IKONOS image data were acquired on July 7th 2001 (Figure 5.8; Table 5.1), in the middle of the fieldwork period, and on June 6th, 2004 (Table 5.1). Both images were acquired on a day with minimal haze, less than 20% cloud cover, and clear water. The imagery was purchased with full 11-bit radiometric resolution, at an angle of 18-degrees off-nadir. The image was radiometrically and geometrically corrected, then resampled using the cubic convolution method provided by Space Imaging. The cubic convolution method calculates the weighted average of the 16 closest pixels to the specified input coordinates, and assigns that value to the output coordinates. This method achieves a more accurate sin(x)/x value than the nearest neighbour or bilinear interpolation. The result is an image that appears sharper than it would if alternative resampling techniques were used (www.pcigeomatics.com).

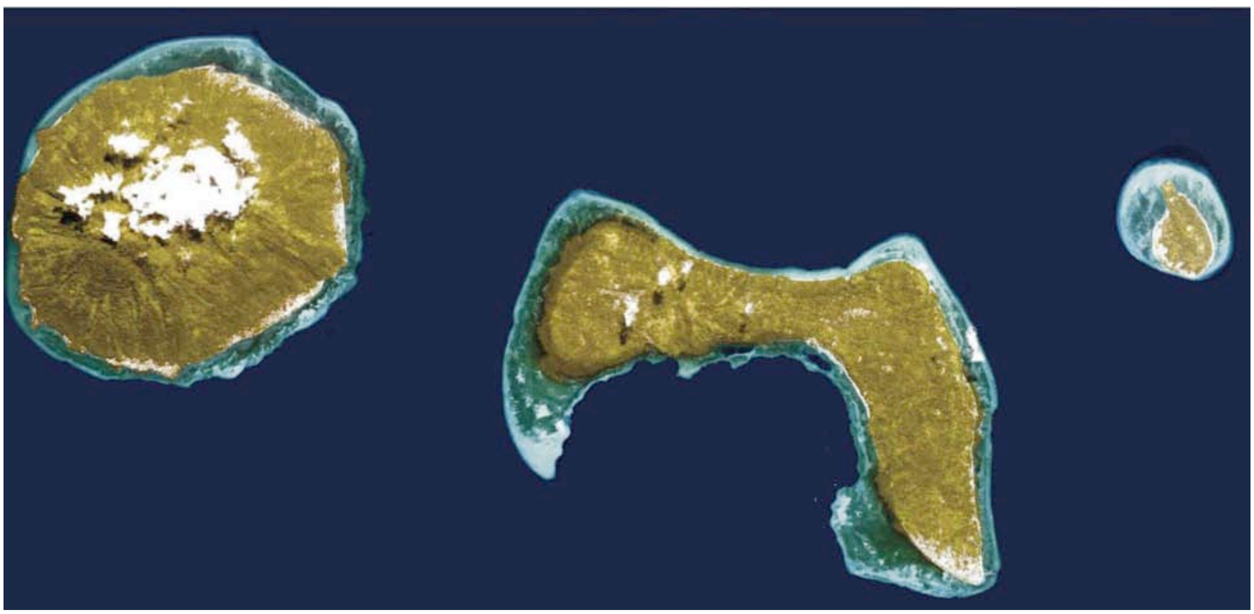

Figure 5.8. IKONOS image captured on July 7, 2001 in four multispectral bands and one panchromatic band.

Table 5.1. IKONOS satellite image details.

IKONOS Band Number	Band	Wavelength	Multispectral or Panchromatic	Resolution (m)
1	Blue	445-516 nm	Multispectral	4
2	Green	506-595 nm	Multispectral	4
3	Red	632-698 nm	Multispectral	4
4	NIR	757-853 nm	Multispectral	4
5	Panchromatic	445-853 nm	Panchromatic	1

5.3.4 IKONOS Image Pre-Processing

The following image pre-processing techniques were applied to both the 2001 and 2004 IKONOS images. A sequence of image preparation and correction techniques were undertaken to provide a high quality image prior to classification. Image subsetting, masking, and depth correction techniques were used to produce image data in physically meaningful units referenced to a known datum. Only a simple atmospheric correction was applied because information on several atmospheric parameters, such as haze content and moisture levels, was not available. In addition, a surface roughness correction was not considered necessary, as wind speeds over the reef flat and crest were consistently below 6 km/h (UNSRAT member, May 2001, personal communication).

5.3.4.1 Image Subsetting and Masking

Bunaken Island and the shallow- and deep-water environment surrounding the island were subsetted from the full image. Before conducting depth corrections or classifications, land, clouds, deep water, boats, and docks were also masked out of the image (Figure 5.9). Masks were created by manually tracing separate polygons for each group of features.

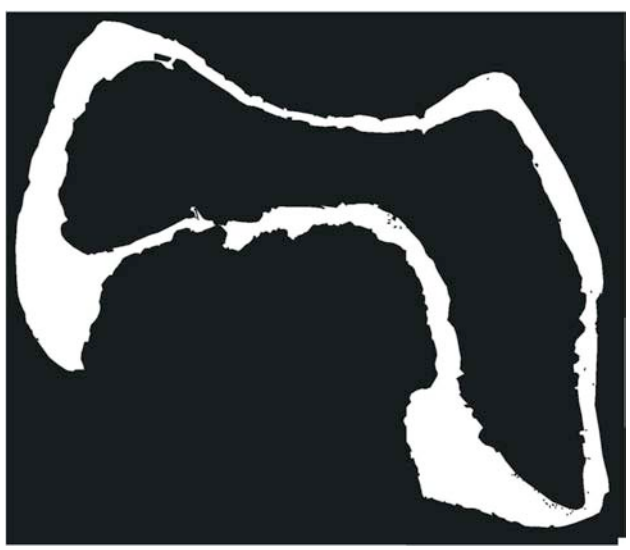

Figure 5.9. Mask of Bunaken Island.

5.3.4.2 Atmospheric and Depth Correction

For many coral reef image analysis studies, an atmospheric correction is conducted prior to depth correction. The atmospheric correction used here involved a dark pixel subtraction that involved sampling a number of pixels from the deep water area, beyond the reef slope, calculating their average and then subtracting this value from all other pixels in each band. Depth correction of IKONOS satellite imagery was done using a semi-empirical approach that is specified in detail in Green *et al.*, 2000, and which is based on Lyzenga's (1978) model. This model extracts bottom-type information using an algorithm that is founded on the assumption that the bottom-reflected radiance is a linear function of the bottom reflectance and an exponential function of water depth. In theory, pixels with the same bottom type, but lying at different depths, fall along a line on a log-transformed plot of radiances in two bands, the slope of the line representing the ratio of diffuse attenuation of the two bands. Pixels representing multiple bottom types will result in a series of parallel lines. Therefore, regardless of depth, all pixels representing the same bottom-type can be assigned the same index-value. There are several drawbacks to this method, however, including interference from multiple reflections from the bottom in bright, shallow depths (Newman, 2001), index values cannot be related to radiance or reflectance measurements, and also, in the case of Bunaken Island, the same bottom type does not recur over a wide range of depths. However, the technique has been successfully applied in other areas (Andréfouët *et al.* 2003) and is used in this study because depth is relatively constant within the tidal flat throughout the scene. This means that the probability of high overall classification accuracy is higher than if no water column correction is applied.

5.3.5 Supervised Classification

In total, 615 ground observation points were used for both images to develop training areas. Training areas were defined as common and specific habitat types that were identified in the field data processing stage. Training areas included the following: 3 classes of coral (<5m, 5-15m, >15m); 3 classes of seagrass (<5m, 5-15m, >15m); 3 classes of sand (<5m, 5-15m, >15m); 3 classes of silt (<5m, 5-15m, >15m); 3 classes of rubble (<5m, 5-15m, >15m), 3 classes of hard rock (<5m, 5-15m, >15m); 1 class for lagoon; 1 class for boulders; 1 class for silt covered coral.

The training areas were used in a supervised maximum likelihood classifier. Only the first three monochromatic bands, at 4 x 4 m spatial resolution, were used in the classification. These included the Blue band (445-516 nm), Green band (506-595 nm), and Red band (632-698 nm). The Region of Interest (ROI) separability function was used to compute the spectral separability between training areas. This function outputs measures in both the Jeffries-Matusita and Transformed Divergences forms (ENVI Version 4.2). A Jeffries-Matusita and Transformed Divergence values are reported for every ROI pair, whilst the bottom of the report shows the ROI pair separability values listed from the least separable pair to the most separable.These measures were used to determine which classes were most similar and therefore most influential in reducing the overall accuracy and increasing the Kappa coefficient. When classes received a value of <1 in the Jeffries-Matusita calculation, a decision to merge classes with similar measures was made. Next, approximately 110 ground observation points not used in the development of training areas, along with data from the photo transects, were used to assess the accuracy of the classification. The accuracy assessment was conducted by placing a grid over the image and computing the Producer's Accuracy and User's Accuracy. Grid-point data were used to build the confusion matrix and to determine the overall classification accuracy.

5.3.6 Change Detection Analysis

The 'Compute Different Map' routine was conducted in ENVI to characterize an increase or decrease in the presence/absence of coral and seagrass in each pixel. The difference is computed by subtracting the 2001 image from the 2004 image, and the habitat classes were marked with change thresholds. Change thresholds were set to 5%. A positive change identifies pixels that were absent in 2001, but present in 2004, while a negative change identifies pixels that were present in 2001, but absent in 2004. The 2001 and 2004 images were initially normalized to a data range between zero and one, and both images were co-registered.

5.4 RESULTS AND DISCUSSION

5.4.1 Field Data Collection and Processing

Field surveys confirmed that there were six common habitat types throughout the shallow-water environment and they could be subclassified into one of three separate depth categories (<5m, 5-15m, and >15m). In addition, three site-specific habitat types were identified, though they were not stratified into subgroups. Of the common habitat types, coral dominates the reef crest that surrounds the west and east sides of the island; seagrass and sand dominate the southeast and southwest corners of the island; boulders are located only along the northern coast.

5.4.2 Image Pre-Processing

The image pre-processing isolated the shallow water environment surrounding Bunaken Island and created a high-quality image for the classification. The depth correction technique was time consuming and required several iterations were conducted. The depth corrected image contained improved correction in bottom reflectance.

5.4.3 Image Processing

Results of the supervised maximum likelihood classification resulted in an image of 21 separate habitat classes. Post classification of the image revealed an overall accuracy of 43% and a Kappa coefficient of 0.78 indicating low spectral separability between classes. Therefore, it was necessary to reduce the number of classes. Using knowledge of the area, as well as a spectral separability of classes measured, the n-dimension Visualizer function in ENVI, 12 classes were selected. These classes consisted of 3 classes of coral (< 5m, 5-15m, > 15m), 3 classes of seagrass (< 5m, 5-15m, >15m), 2 classes of sand (< 5m and 5-15m), silt, lagoon, hard rock, and boulders. This resulted in an overall accuracy of 65% and a Kappa coefficient of 0.56. The confusion matrix is presented in Table 5.2.

Table 5.2. Image accuracy for 12 classes in both the 2001 and 2004 imagery following a reduction in habitat class numbers.

	2001 Imagery		2004 Imagery	
Class	**Prod. Accuracy (Percent)**	**User Accuracy (Percent)**	**Prod. Accuracy (Percent)**	**User Accuracy (Percent)**
Coral (<5m)	18.65	43.73	19.23	43.76
Coral (5-15m)	33.33	81.75	31.98	79.86
Coral (>15m)	82.82	90.38	81.88	90.45
Seagrass (<5m)	68.79	68.33	69.23	67.82
Seagrass (5-15m)	79.01	95.71	78.77	96.65
Seagrass (>15m)	71.05	6.34	70.40	6.45
Sand (<5m)	99.50	57.00	98.34	56.34
Sand (5-15m)	66.38	83.35	68.03	85.02
Silt	78.05	2.96	77.77	2.23
Lagoon	55.09	4.59	54.92	3.69
Hard Rock	60.38	3.08	62.06	3.98
Boulders	37.50	3.92	36.34	2.56

Although the accuracy of habitats improved following the reduction of classes, the ROI separability function revealed spectral confusion between coral at different depths, seagrass at different depths, coral and hard rock, and seagrass and boulders, and sand (< 5m) and coral. As a result, paired classes with ROI separability values less than 1.5 were merged with other classes or removed. This meant the following: sand < 5m was deleted; coral (5-15m) and coral (> 15m) were merged; all seagrass classes including boulders were merged; coral (< 5m) and hard rock classes were merged.

Following merging and deletion of classes, 6 classes remained and included: coral (< 5m), coral (5-15 m), seagrass, sand, silt, and rubble. The overall accuracy was 73% with a Kappa coefficient of 0.49. Results from the confusion matrix indicated that all classes had a high probability that any pixel in that category has been correctly classified (Producer's Accuracy), and that all classes had a high probability that a pixel classified in the image actually represents that habitat type *in situ* (User's Accuracy) (Table 5.3).

Table 5.3 Producer and User Accuracy of final habitat types (2001 and 2004 habitat maps).

	2001 Imagery		**2004 Imagery**	
Class	**Prod. Accuracy**	**User Accuracy**	**Prod. Accuracy**	**User Accuracy**
	(Percent)	**(Percent)**	**(Percent)**	**(Percent)**
Coral (<5m)	81.39	90.23	82.34	91.32
Coral (5-15m)	75.96	80.12	76.45	81.58
Seagrass	77.26	78.14	77.45	79.43
Sand	79.81	82.62	78.65	81.04
Silt	97.56	72.75	97.36	73.02
Lagoon	75.45	73.04	77.39	74.09

In addition, results from the ROI Separability measure also indicated that high levels (>1.8) of separability were evident between all classes. Accuracy levels, Kappa coefficient, and ROI separability results were within a range found within IKONOS coral reef remote sensing studies (Andréfouët *et al.*, 2001; Kutser *et al.* 2006). Therefore, the number of classes was not reduced further. The final habitat maps are provided in Figure 5.10 and figure 5.11 and overall classification accuracies are 78% and 81%, respectively.

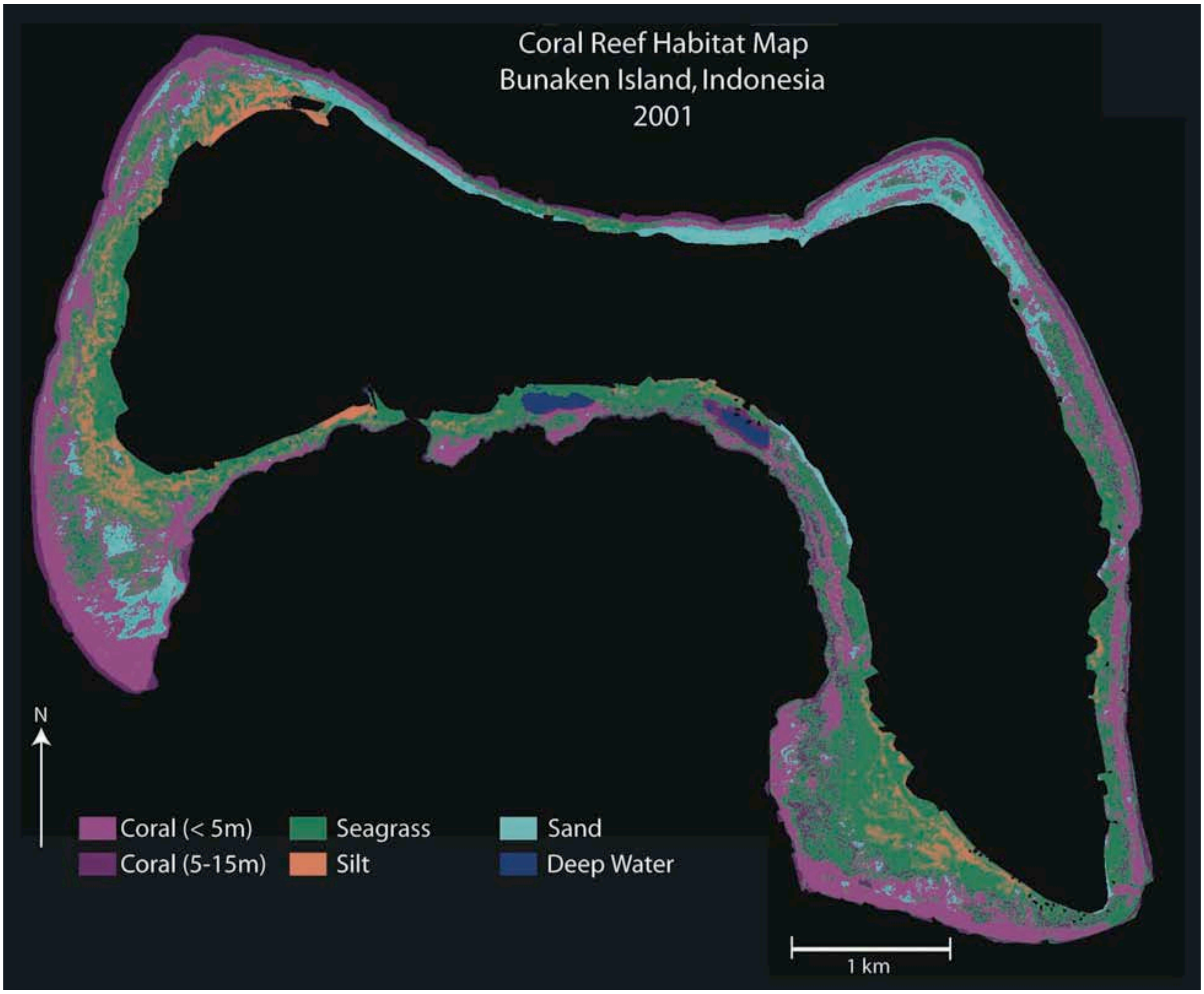

Figure 5.10. Habitat map of the coral reef ecosystem surrounding Bunaken Island, Indonesia (2001).

According to the 2001 habitat map, the coral habitat is distributed around the island and is located primarily within the reef crest and appears to penetrate the reef flat along the east and west coasts and southeast and southwest corners of the island. The seagrass habitat is also found surrounding the island, dominating the tidal flat in most regions except for the north coast, especially the northeast corner of the island where sand dominates. Sand is found dominating the reef flat in the southwest corner of the island. Silt is located primarily along the west coast and southeast corner of the island, again within the reef flat. There are two sites identified as 'lagoon'. At these locations, water depth is greater than 15 m and coral rubble resides at the bottom of each lagoon. The colours chosen to display the substrate types were selected within the colour palette in ENVI. Colour selection was based on the 'true' colour of the substrate when viewed in the field.

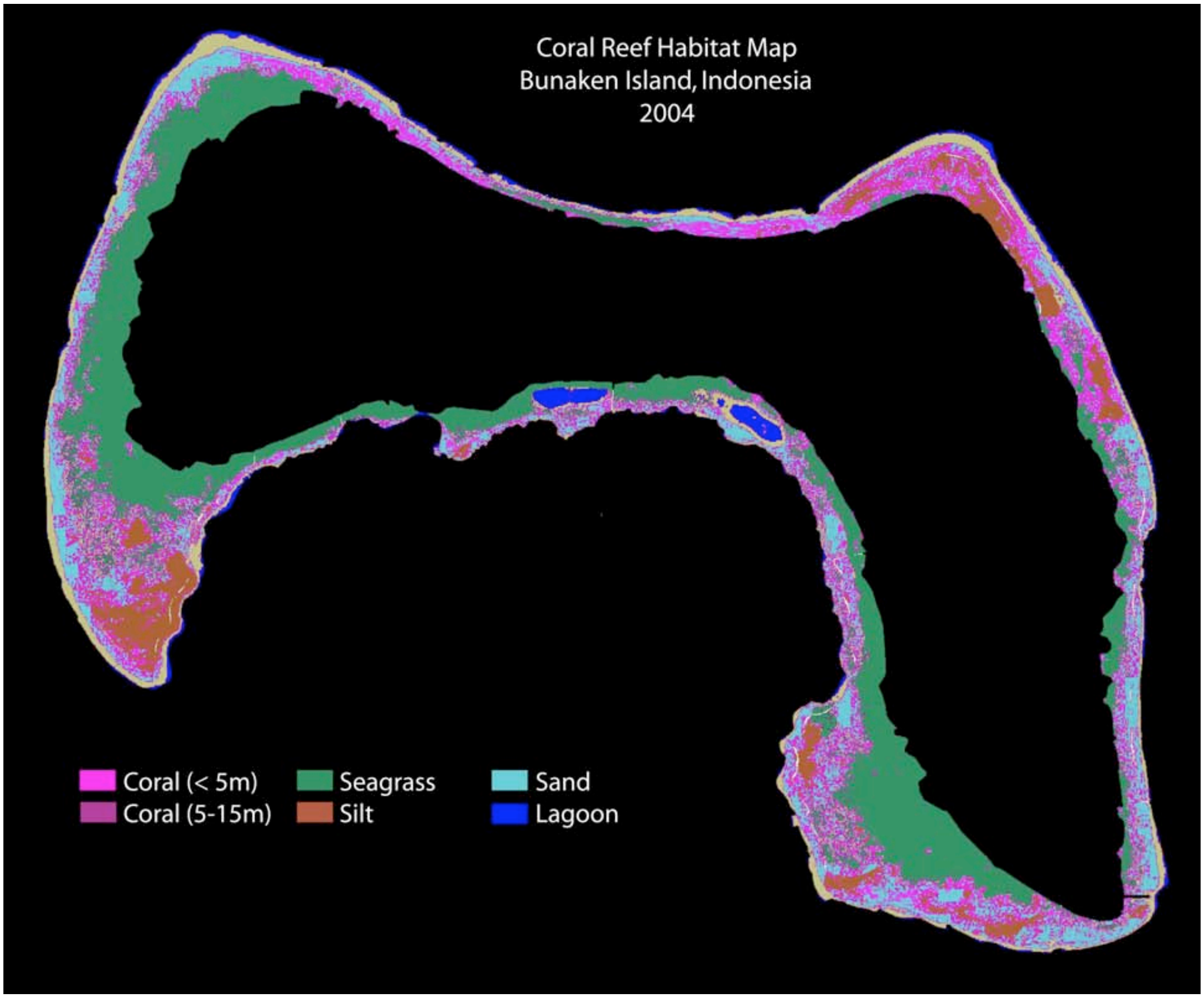

Figure 5.11. Habitat map of the coral reef ecosystem surrounding Bunaken Island, Indonesia (2004).

According to the 2004 habitat map, the coral habitat is distributed around the island and is located primarily within the reef crest. Coral habitat is also located along the reef flat along the east and west coasts and southeast and southwest corners of the island. Seagrass habitat dominates the reef flat in the southeast corner and west coast. Sand is found dominating the reef flat in the southwest corner of the island and the reef crest in the southeast and southwest corners. Silt is located primarily along the west coast and southeast corner of the island, again within the reef flat. There are two sites identified as ‘lagoon’. At these locations, water depth is greater than 15 m and coral rubble resides at the bottom of each lagoon. The colours chosen to display the substrate types were selected within the colour palette in ENVI. Colour selection was based on the 'true' colour of the substrate when viewed in the field.

5.4.4 Change Detection Analysis

Overall, more areas experienced an increase in both coral and seagrass habitats between 2001 and 2004. *In situ* data supports this finding and shows an increase in coral of 11% and an increase in seagrass of 7% between. It is important to note that a change in coral or seagrass of less than 5% represents 'no change' in this analysis. The threshold of 5% is used to accommodate variation in atmospheric conditions between the two images and co-registration error. Therefore, the change in seagrass might also be considered insignificant because of the low change value.

Although calculating the overall amount of change is valuable, for the purposes of this study the location of change is of greater interest. Results of the change detection analysis are illustrated below in two separate images (areas with an increase in coral habitats; areas with an increase in seagrass) (Figure 5.12 and Figure 5.13). The overall root mean square error was calculated at < 1 pixel width and this low value is attributed to the fact that the imagery was registered to local charts. Several remote sensing studies, however, have found that CASI is the only remote sensing method that has the capability to accurately monitor changes in seagrass (Green *et al.*, 2000; Mumby *et al.*, 2004), therefore, the change detection results presented here, especially of seagrass, should be noted with caution. The images below illustrate locations that experienced only an increase in coral and seagrass because only these habitats and only an areas that experienced an increase in these habitats through time were targeted for this study. In otherwords, only this information was required in the methods of subsequent stages.

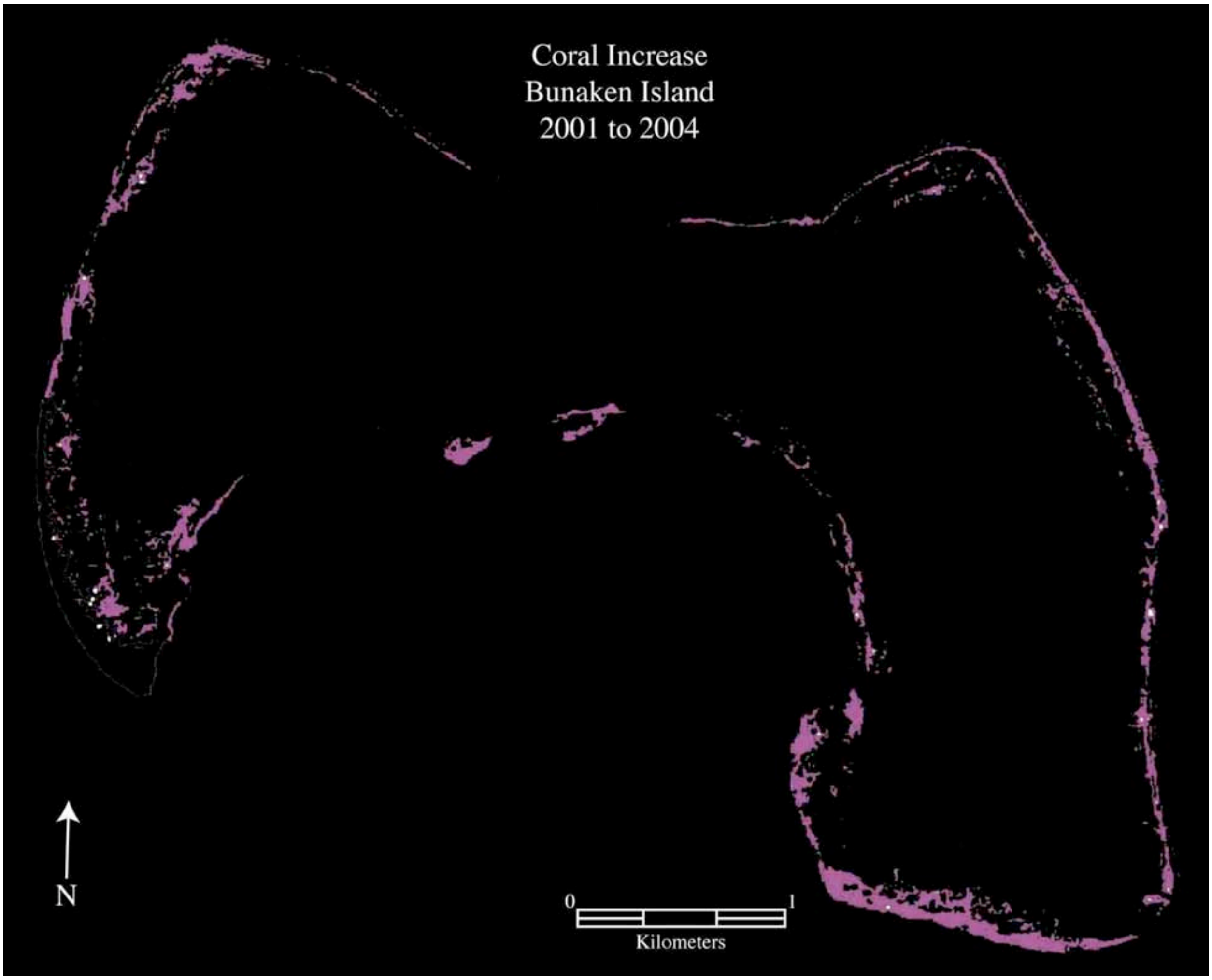

Figure 5.12. Locations where the Coral habitat classes (Coral < 5m and Coral 5-15 m) experienced an increase between 2001 and 2004.

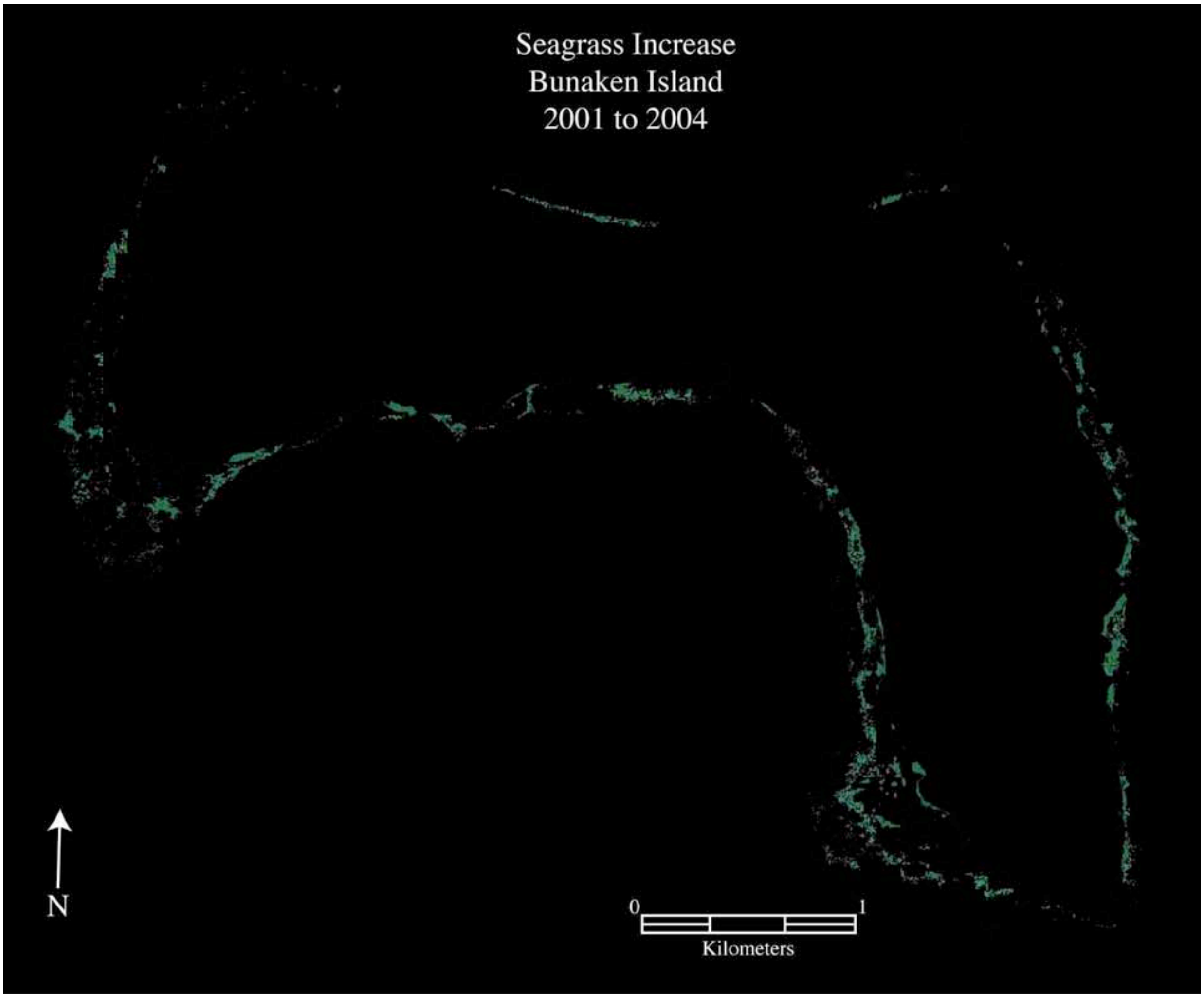

Figure 5.13. Locations where only the Seagrass habitat type experienced an increase between 2001 and 2004.

5.5 EVALUATION OF THE RESEARCH

In this chapter, a map of the habitat types located within the shallow-water environment surrounding Bunaken Island is developed. This means the spatial location and extent of coral, seagrass, and sand, dominate substrate types, are depicted within a single image. The method presented here is commonly used in coral reef remote sensing studies, which have produced similar results.

5.5.1 Strengths

- Considerable field investigation permitted significant familiarity with specific habitat types and the atmospheric and aquatic conditions that the habitats experience.
- Using 615 ground control points to identify training areas was useful for creating a habitat map with a high user, producer, and overall accuracies.
- Starting with a large number of habitat types and reducing these habitat types using an ROI separability measure ensured that final habitat types were selected based on a systematic measure that is founded in spectral separability.

5.5.2 Weaknesses

- The average error of the GPS is 2-3 metres. Knowing this, when possible, GPS measurements were taken from the main dock on the south coast of the island from 10-2 on several days when GPS coordinates were also taken in each geomorphological zone. The main dock was clearly visible within the imagery and the intention was to use the dock as a permanent target from which one gps unit would measure coordinates throughout the day, while a second gps unit would be used to measure coordinates in the field. Because of the challenges associated with leaving a gps unit unattended, this goal was not achieved.
- For several ground observation points, a full suite of photographs, depth measurements, and coral identification was incomplete. Therefore, it is possible that some polygons were incorrectly selected, causing an increase in spectral overlap between classes and a decrease in the overall accuracy.

5.5.3 Conclusion and Future Research

The focus of this research has been on habitat map development of the coral reef ecosystem surrounding Bunaken Island, using both field and IKONOS image data. In the following chapters, the habitat maps and change analysis maps are used to investigate stakeholder receptivity. Comments about map content and presentation will be identified, and discussions about the applicability of the habitat map to current and future Bunaken Island management projects will be described. This chapter concludes the first stage in the four-step strategy.

CHAPTER SIX:
STAKEHOLDER RECEPTIVITY TO THE CORAL REEF HABITAT MAP

SUMMARY

This is the second stage in a strategy that guides the use of remotely-sensed information in coral reef management for Bunaken Island. In this chapter, the habitat map (Chapter Five) is used to investigate stakeholder receptivity. Informal Interviews, Focus Group Discussions, and Participant Observation techniques were used to gather qualitative data. The data were organized into map content, map presentation, and map applicability categories, which were examined for common themes. The objective was to acquire both general and specific feedback from stakeholders in the categories identified above. The findings from this research were then used to identify linkages between habitats and management questions, which are described in detail in Chapter Seven.

6.1 STUDY AREA

In this chapter, the stakeholder groups of Bunaken Island, Indonesia, specifically those groups involved in local coral reef management projects are of most interest. Because the degree of involvement in management projects varies between groups, inclusion in this research was based on whether a group has involved itself in coral reef management projects at some time since the inception of Bunaken National Park (1991). Such stakeholder groups have been identified in earlier studies (Lee 2001; Erdmann *et al.*, 2002; DeVantier and Turak, 2004), and by local and foreign NGOs facilitating coral reef management projects on Bunaken Island. Using these studies and advice from NGOs, the stakeholder groups identified for this study include the North Sulawesi Watersports Association (NSWA), which includes 10 member dive operations which actively seek strategies to prevent coral reef deterioration; the Bunaken Concerned Citizens Forum (BCCF), which includes 3,000 villagers on Bunaken Island who are represented by two elected officials who communicate the group's concerns about economic and food security. These two stakeholder groups are the largest, and most intensive users of the marine resources surrounding Bunaken Island (Erdmann *et al.*, 2001). Secondary stakeholder groups include the Ministry of Tourism (MofT), Scream (local NGO), Natural Resources Management (NRM III), and Universitas Sam Ratulangi (UNSRAT). The Bunaken National Park Management Board

(BNPMB) is also considered a secondary stakeholder group, which included representatives from NSWA, BCCF, and the municipal and provincial government.

In this research, a stakeholder is defined as an individual belonging to one of the previously identified stakeholder groups, who has some interest in learning about how the habitat map may contribute to current and future coral reef management projects on Bunaken Island. Stakeholders were either self-selected through having expressed an interest in the project, or were chosen by the researcher through a process that utilized 'authority within the stakeholder group' and 'knowledge of coral reef management projects' as measures for selection. The researcher selected representatives of each stakeholder group, who were selected by group consensus, and were knowledgeable about coral reef management projects. Members of NRM III provided assistance in the identification of representatives.

6.2 METHODS AND MATERIALS

In 2004, qualitative data were collected by the researcher and a research assistant Defy Caroles (member of NRM III). Data were collected for members of each stakeholder group. Qualitative data gathering tools included informal interviews, focus group discussions, and participant observation. The data collection processes used the principles in the Participatory Rural Appraisal (PRA) methodologies (Chambers and Guijt, 1998). The objective was to investigate stakeholder receptivity to the habitat map (Figure 6.1), in three broad categories: map content, map presentation, and map applicability to current and future coral reef management projects. The map that was used for this stage was the coral reef habitat map that was developed in Stage One. The colours used to represent each class were selected by approximating the 'true' colour of the class on the ground. Seagrass, for example, appears as dark green, coral appears as magenta, and lagoon appears as dark blue. For sand, a light blue colour was selected to contrast well with the magenta and black surrounding colours. The map was printed on a standard 8.5'x11' sheet of paper and laminated.

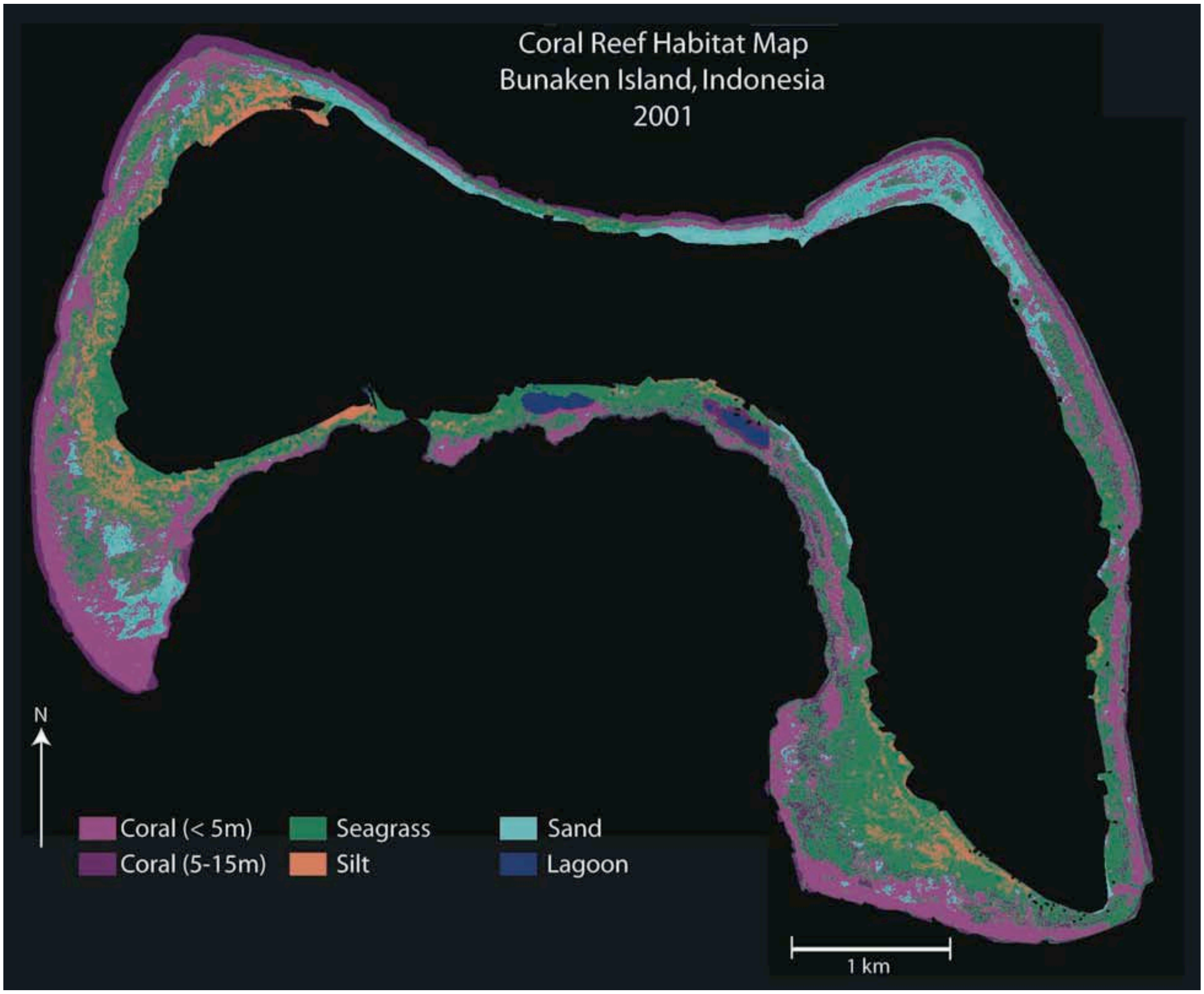

Figure 6.1. Coral reef habitat map used to investigate stakeholder receptivity.

6.2.1 Qualitative Data Collection

In 2004, the number of respondents interviewed was 36: 7 from NSWA, 10 from BCCF, 1 from the Ministry of Tourism, 1 from Scream, 5 from NRM III, 2 from UNSRAT, and 9 from BNPMB. Focus group discussions were held with five different stakeholder groups: NSWA, BCCF, NRM III, UNSRAT, and BNPMB. Participant observation was conducted at three separate stakeholder meetings that included NSWA, BCCF, and BNPMB. Focus group discussions and participant observation were not conducted with the Ministry of Tourism because they were not interested in participating in the project, nor with Scream; however, several MofT and Scream representatives attended meetings held at the NRM III office.

6.2.1.1 Informal Interviews

During the months of May through June in 2004, interviews were held on Bunaken Island and in the city of Manado and ranged in duration from 30 to 60 minutes. The total number of respondents interviewed was 36. Individuals were selected via a set of criteria (described below). Extending the selection to individuals outside of these criteria was regarded with concern. The researcher had been informed by long-standing members of NRM III that discussions about coral reef management with some stakeholders might suggest the development of a new management or a new zonation plan, thereby inciting unnecessary concern within the community.

Informal interviews were conducted according to the following process:

1. Respondents were carefully identified by using 'authority in the community' and 'knowledge of local coral reef management projects' as selection criteria. This process relied upon input from long-standing members of NRM III and UNSRAT (Mapping Department), who had over 10 years of experience working with stakeholders within the community on coral reef management projects.
2. Respondents were contacted by phone or in person, informed of the objectives of the project and anticipated use of the data, and then asked whether they would participate in an informal interview.
3. Interviews began with an introduction about the habitat map and how it was developed, and then followed with informal interview questions (see below).
4. The interviews were conducted in both English and Bahasa Indonesia, and responses were recorded by taking written notes. When the researcher was uncertain about a key phrase or comment, the respondent was asked to rephrase the comment. Each interview was conducted slightly differently, as questions were rephrased or modified to accommodate the knowledge and perspective of the respondent; however, the objective of all of the interviews was consistent.
5. Following each interview, the information was summarized independently of the respondent, and key phrases and comments were highlighted.
6. Findings were discussed with the research assistant and members of NRM III, who had worked with many of the respondents in previous projects. The purpose of this task was to

confirm statements, clarify phrases and terms, and elaborate on comments that were made by the respondent, but were insufficiently understood by the researcher.

Interview questions were prepared ahead of time, and authorized by the Office of Ethics at the University of Waterloo. The following questions were asked of each respondent, and the coral reef habitat map (Figure 6.1) was used as the focal point.

1. With what habitat types are you most/least familiar? With what habitat types are you most spatially familiar?
2. What is your impression of the map? Do the colours clearly identify the different habitat types? Can you identify your village/markets/docks? Do the colours have different meanings to you?
3. Could this map contribute to current management projects of Bunaken's coral reefs? What questions/concerns do you have of Bunaken's reefs? Could this map address these questions/concerns? Could this map contribute to future or pending management projects?

In addition to these questions, additional questions within the three categories were created during the interview, allowing the interviewer and the person being interviewed the flexibility to respond to and to ask specific questions. Moreover, respondents were encouraged to ask questions about the habitat types, how the habitats were defined, the colours used to represent the habitats, as well as the processes used to create the map, the type of imagery, and the cost of the imagery.

To address the challenges posited by cross-cultural communication, the researcher attended a one-month intensive language training course at Realia in Yogyakarta to learn formal Bahasa Indonesia. Training included one-on-one lessons with Bahasa Indonesia instructors. Lessons were daily and held from 8 until 3 pm in a school setting. At the end of the day, the researcher returned to an Indonesian home, within which residents spoke minimal English. As a result, the researcher continued learning the formal language after class, In 2004, the researcher continued language lessons at UNSRAT with English-Bahasa instructors. The language training was critical to the success of this research. Learning the formal language provided the researcher with either an opportunity to speak directly with stakeholders or to hire local personnel, provide training, and conduct group meetings in the local language. Replication of this research is highly dependent on the researcher being able to communicate effectively in the local language.

6.2.1.2 Focus Group Discussions

During May and June of 2004, five presentations were made to different stakeholder groups to acquire feedback on map content, presentation, and map applicability to current and future management projects. The presentations also provided an opportunity to discuss the process of remote sensing and the development of the habitat map. The first presentation was given to NRM III personnel in Manado, while the second was given to faculty members from UNSRAT (Mapping and Biology Departments). The third presentation was given to members of BCCF, who had gathered for a management meeting in Alung Banoa, while the fourth was given to NSWA members in Manado. The final presentation was to members of the BNPMB, who had gathered in Manado to discuss the success of current management projects and the redirection of Park funds for student scholarships. Most meetings had been organized by each group's primary coordinator to discuss an issue about Bunaken's coral reefs. The coordinator reserved 15 to 30 minutes at the end of each meeting for the researchers' presentations. For each presentation, a pre-selected member of NRM III was asked to attend and transcribe comments.

6.2.1.3 Participant Observation

By the end of June 2004, the researcher attended three stakeholder meetings (NSWA, BCCF, and BNPMB) that involved discussions about coral reef management; researcher participation in these meetings had been passive. The researcher did not participate in discussions. At each meeting, the attendees were identified, the speakers were noted, the topics of conversation and described in detail when possible, and the means of decision making was identified and transcribed. Attention was given to discussions on coral reef management projects and the type of data needed or used for building or enhancing these projects. Attention was also given to community- or aerial- or satellite-based mapping projects. Notes were taken throughout the meetings by the researcher as well as by a pre-selected member of NRM III, who had been hired for the duration of the study.

6.3 QUALITATIVE DATA PROCESSING

The researcher sometimes experienced difficulty understanding several terms and phrases used by respondents. To address this, translation assistance was provided by the research assistant and members of NRM III. Because of NRM III's long-standing involvement in the community and facilitation of numerous community-integrated coral reef management projects, members were asked to assist in processing the informal interview data. First, the information was translated into English, and then organized by date. Next, the information was transcribed directly onto the computer, and photographs were labeled. The challenge was to categorize the comments. With assistance from NRM III personnel, the comments were grouped into categories that best fit the respondent's statements. This technique is used to identify 'indicator' categories: those categories of most value and interest to the respondent, and that occur amongst respondents. Ideally, any qualitative analysis software package, such as NUD*IST or NVIVO (www.qsrinternational.com), could be used to categorize the data, although, given the small data set, a software package was deemed unnecessary.

Focus group discussion data were also first translated into English, and then organized by date. The information was transcribed directly onto the computer, and photographs were labeled. Where phrases and terms were unknown, members of NRM III provided assistance.

Participant observation data gathered during stakeholder meetings were first translated, and then transcribed directly onto the computer. These notes were less orderly than the notes taken during focus group discussions or during informal interviews because they included descriptions of the contents and format of the meeting. In addition, each meeting was different: they had different attendees, different formats, and different topics of discussion. For processing, the data were organized into categories including attendance, duration of meeting, discussion topics, coral reef management projects and data requirements, and mapping projects. The last category was decision making, which was used to describe how decisions were made, who contributed to the decisions, what information was considered, and who made the final decisions.

6.4 RESULTS

6.4.1 Informal Interviews

All respondents indicated interest in this study and a willingness to answer questions candidly. There were often numerous, as well as animated, comments made when respondents were asked about the applicability of the habitat map to current and future coral reef management projects. During interviews, it was evident that respondents were unconcerned with whether their comments were contradictory to governmental regulations. Respondents were seemingly open in expressing their views. Following organization of the data into the three categorizes, map content, map presentation, and map applicability, several dominant themes emerged. These themes are described in the sections below.

6.4.1.1 Map Content

NSWA and BCCF respondents stated that they were familiar with the spatial location of coral reefs, seagrass, and sand within the coastal environment surrounding Bunaken Island. These statements were supported by comments made by members of NRM III, who had regularly worked with these respondents and members of both stakeholder groups on developing and implementing coral reef management projects. These statements were also supported by the observations made of boating activity. Dive operators and fishers knew the precise location of boat channels, zonation boundaries, and fishing and dive locations.

> "The community knows where their resources are. They've been living on Bunaken Island their entire lives. Only recently are the young adults moving to Manado to go to university. The adults are still on the island, and they and their parents know where the resources are because they have depended on them for their livelihood. They also depend on them for medicinal purposes. The grandparents know which habitat will provide seahorses. Seahorses are an important part of their tradition." NRM III Respondent.

> "People know where the resources [coral reef] are located. We have been working with maps that tell us this for a very long time. We don't need another map showing us the location of the resources." Scream Respondent.

> "We know where the resources are. I collect resources daily. I know where I can find the fish and where the fish will be healthy. I don't need a map to show me that. Wait, your map doesn't show me that!" BCCF Respondent.

The two respondents from UNSRAT commented on their familiarity with the spatial location of coral, seagrass, and sand, and expressed interest in identifying the location of coral reef species that are recognized as 'threatened' or 'rare' in the IUCN Red List (www.iucnredlist.com). Both noted that general classification categories, as they suggested were provided by the habitat map, were not of value to the local scientific community because such maps were already locally available.

> "Although your map shows us where we can find some of the main resources, it doesn't tell us which species are in the coral class. We need to know the species that are in each class. Species information is critical to developing monitoring and protection programs, and to capture international attention and funding." UNSRAT Respondent.

The Ministry of Tourism respondents were familiar with the contents of the habitat map, although they admitted to having visited Bunaken Island only "two or three times". Respondents indicated that habitat maps were common at both municipal and provincial levels. Moreover, historic and present community-based mapping projects revealed habitat information in "greater detail" than the coral reef habitat map in this study.

Comments from the respondents suggest that they are familiar with the broad habitat classes used in the habitat map and that they have viewed similar categories in local maps such as the habitat map developed by the Japan International Cooperation Agency (JICA), which was commissioned to generate a habitat map in 2002 (Figure 6.3), and the community-based habitat map developed by faculty members and students from UNSRAT (Figure 6.2). In addition, within each community a habitat map is posted in government buildings and depicts the spatial location and extent of broad-based habitat classes (Figure 6.4).

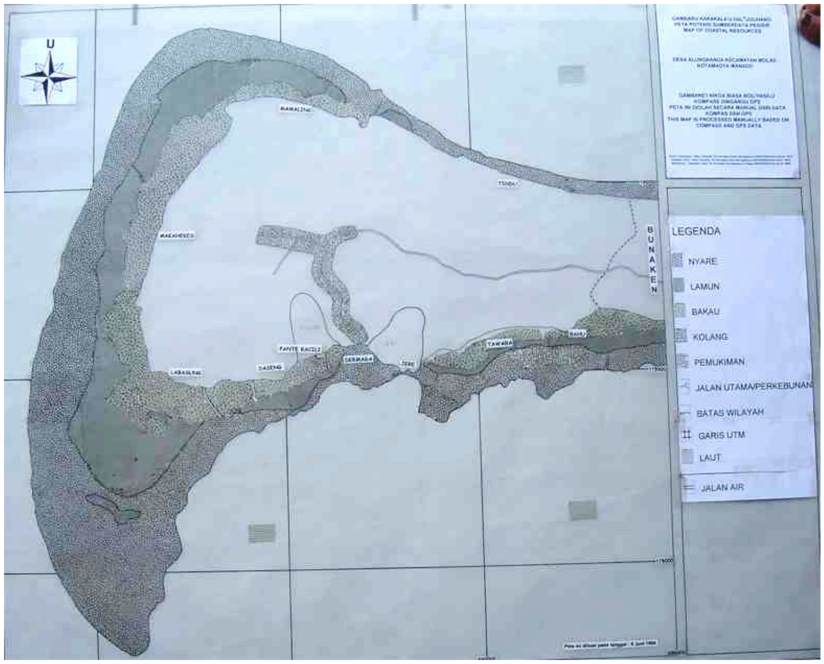

Figure 6.2. Map produced by faculty and students at UNSRAT depicting the spatial location and extent of coastal features in the western half of Bunaken Island.

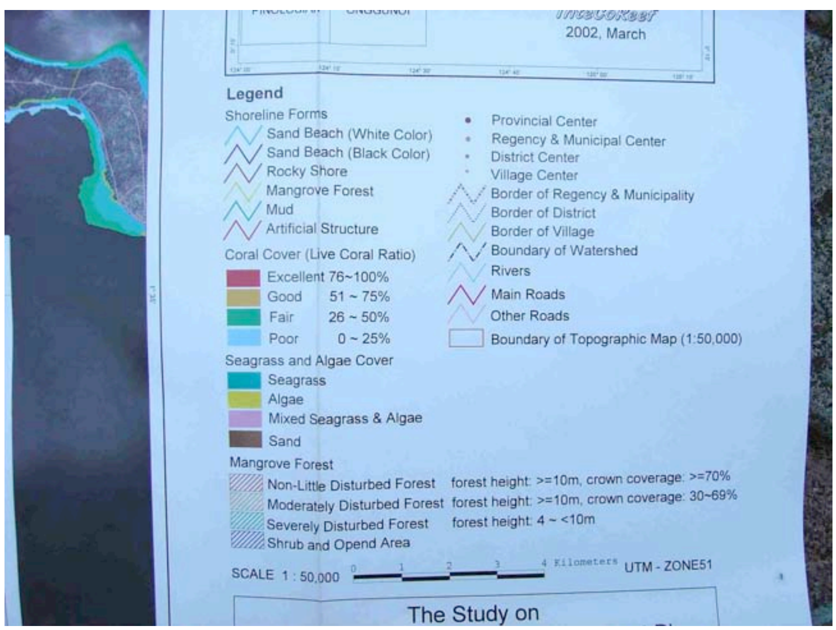

Figure 6.3. Habitat map legend produced by JICA in 2002.

Figure 6.4. Map of both marine and terrestrial features created by UNSRAT and Government representatives for the villagers of Alung Banua.

6.4.1.2 Map Presentation

Responses from all respondents suggested a familiarity with maps, as well as an ability to read maps with different formats, and interpret maps with variable content. Common maps, available to all stakeholder groups, included dive maps, coral species maps, zonation maps, and habitat maps (Figure 6.5-6.8). Common themes amongst these maps included a north-orientation, legend, and variation in colour to represent different features. Therefore, when respondents were presented with the IKONOS coral reef habitat map they were quickly able to identify the location of villages, docks, markets, churches, while respondents who spent a considerable amount of time out on the water were able to identify the location of boat channels, dive sites, and common fishing locations.

Figure 6.5. Zonation map and zone regulations poster used in every village on Bunaken island.

Figure 6.6. Map of Bunaken Island posted at the main entry point to the Island.

Figure 6.7. Dive site map at Two Fish dive resort.

Figure 6.8. Habitat map produced by the Coral Reef Management Project, North Sulawesi.

Members of BCCF and NSWA are familiar with the marine environment because of their repeated use of marine resources. The primary objective of BCCF members is to acquire commercially valuable fish and sell these fish in the market, while the objective of NSWA members is to take tourists to dive sites that surround the island. As a result, members of both groups are familiar with the spatial location of marine resources.

> "We visit the dive sites each day. We see how the coral changes, and we look for specific fish to show the tourists. The tourists want to see the bigger fish, like the sharks. So, we take them to sites where the wall drops off quickly and the current is fast. So, we know these sites best." NSWA Respondent.

> "We spend our time catching fish in the deep waters. This is where we can catch Tuna and Skipjack and sell them in the market in Manado. We do not spend our time around the reef. Only the elders do that. The elders catch reef fish sometimes and bring them home to their families. The big fish are out in the deep water, so we travel to the deep ocean." BCCF Respondent.

Although the majority of respondents were familiar with reading different maps, the comments suggested that they were dependent upon specific cartographic symbols to orientate them to the map. Many respondents' first comments were about the lack of cartographic symbols and place names on the habitat map, while additional comments were that there were not enough references to fully understand the mapped habitats.

> "The map does not show the zones! I cannot read this map clearly because the zones are not here. You will see that most of the maps we use show the zones." BNPMB Respondent.

> "The dive sites are missing from your map. We need to see the dive sites to be able to talk more specifically about each spot. If you put the dive sites on this map, I will be able to better explain the types of activities that go on there." NSWA Respondent.

> "How can I use the map if I can't see where I live? This map does not show some important places. You need to show the docks, the villages, and the boats. We need to see where we live. We need a map that contains true colour features." BCCF Respondent.

When this respondent was questioned more about what was meant by ‘real’, the respondent suggested the use of icons to represent the location of the villages or a clearer view of the villages. The respondent was suggesting that the pixilated view of the village was insufficient.

A summary of appropriate cartographic features, as stated by the respondents, which would provide adequate orientation for the reader is provided below (Table 6.1). The general orientation feature column includes features that were noted by all respondents, while the specific orientation features column includes only those features specifically noted by respondents in each stakeholder group.

Table 6.1. A summary of general and specific orientation features that would assist respondents in orientating him/herself to the habitat map.

<table>
<tr><th>Stakeholder Group</th><th>General
Orientation Features</th><th>Specific
Orientation Features</th></tr>
<tr><td>Dive Operators</td><td rowspan="6">• Land
• Docks
• Markets
• Churches
• Villages
• Mosques
• Deep Water</td><td>• Dive Sites
• Zonation Plan
• Cuts in Reef Crest</td></tr>
<tr><td>Fishers</td><td>• Dive Sites
• Zonation Plan
• Cuts in Reef Crest</td></tr>
<tr><td>Government Representative</td><td>• Zonation Plan</td></tr>
<tr><td>Board Member</td><td>• Zonation Plan</td></tr>
<tr><td>Scream (Local NGO)</td><td>• Zonation Plan</td></tr>
<tr><td>NRM III (Foreign NGO)</td><td>• Dive Sites
• Zonation Plan</td></tr>
</table>

Concerns over the relative and absolute location also became evident during interviews. Respondents commented on the need to identify the location of dive sites or zone boundaries; however, when they pointed out these locations on the map, the locations often did not correspond to the site or zones’ absolute locations. Respondents were asked to point out additional sites and zones, and, again, they did not correspond. Next, respondents were asked to elaborate on the markers they use, while out on the water, to guide their boats across the reef crest. Respondents said they used mangroves, houses, beached boats, and cuts in the reef crest. The cuts were created by the force of the receding tide and then expanded by boat traffic.

6.4.1.3 Map Applicability to Current and Future Management Projects

Most respondents were visibly excited to contribute ideas on how the habitat map could be used to contribute to current and future management projects; respondents spoke with confidence when asked to discuss the habitat map in relation to management. During several interviews, the discussion about map content and/or map presentation was disregarded, and, instead, respondents spoke about mapping applications. Although some suggestions were not possible, respondents were not corrected. Instead, the respondents were asked to provide as many applications as possible, and to clarify meanings when necessary.

> "Having a map that detailed the location of habitats would be useful for establishing a baseline of coral reef habitats. We could use this to map the location of features now and whether or not they are moving over time." BNPMB Respondent.

> "This is a great map to determine how much of each class is in each zone. We need to know the distribution of seagrass around the island and in each zone, and you can tell us that." BCCF Respondent.

> "We can use this map to identify species at risk. This would be a valuable contribution to our current management efforts." UNSRAT Respondent.

> "Your map can be used to identify the location of the Coelacanth species. I have seen the Coelacanth, and you can identify its habitat, what it eats, and where it goes. Between Manado Tua and Bunaken, we think it lives there." BCCF Respondent.

> "We can use this map to identify how many mangroves have been cut down. Mangroves are protected on Bunaken Island. No one should be building anymore. Some people still build and they are not allowed. We can learn about the mangroves." Ministry of Tourism Respondent.

There were numerous comments provided by respondents, too many to transcribe here, about the applicability of the habitat map to current and future management projects. To address this, the following table provides a summary of the comments (Table 6.2). Generally, the comments suggest that the respondents: (1) have a great deal of interest in the habitat map, (2) have an understanding of how the map can be used -- to identify spatial location and extent and to assess change in habitats, (3) view the habitat map as a useful tool for contributing to a number of management projects, but (4) misunderstand the capabilities of the satellite image to map the spatial location of habitats, or to assess changes in habitats.

Table 6.2. Suggested applications of the habitat map to coral reef management project objectives by stakeholder groups.

Respondent Group	Current Management Projects	Future Management Projects
NSWA	• to investigate the quality of the dive sites. • to evaluate how the dive sites are changing through time. • to identify areas of shallow, sand for dive courses.	• to assess the impact of increased boat traffic on coral condition at each dive site and in each zone. • to assess the condition of coral reefs in areas where there is considerable conflict between dive operators and fishers. • to communicate to non-NSWA member dive sites that have rapid coral reef deterioration due to high use.
BCCF	• to assess the change in seagrass spatial extent. • to assess whether there has been a rise in sea level. • to identify the change in mangrove extent. • to examine the spatial extent of coral reefs nearby Bunaken and Alung Banoa Village.	• to assess the change in seagrass extent. • to identify areas from which medicinal organisms can be extracted. • to assess the condition of stocks of large fish such as Tuna and Skipjack.
Ministry of Tourism	• to provide an overall view of Bunaken Island to tourists. • to identify how the tourists are impacting the reef.	• to illustrate to the government the pristine condition of coastal resources surrounding Bunaken Island.

Continued from Table 6.2.

BNPMB	• to evaluate the zonation plan. • to evaluate coral condition in each zone. • to identify zones with the poorest coral reef condition. • to identify grouper monitoring locations and to assess how the sites have changed through time. • to monitor the impact of garbage from Manado on the reefs.	• to evaluate the zonation plan. • to identify how the grouper monitoring sites have changed through time. • to identify areas where coral condition is poor. • to generate maps for use in villages.
Scream (Local NGO)	• to identify the number of boat scars along the reef crest.	• to identify the impact of foreign fishing vessels on the reef.
NRM III (Foreign NGO)	• to validate and evaluate the zonation plan. • to monitor the condition of eco-reefs and to identify new locations for eco-reef placement.	• to provide patrols with a map of the zonation plan that is linked to a GPS unit • to confirm their location when out on the water. • to communicate reef condition to community members during socialization processes.
Faculty Member (UNSRAT)	• to identify species at risk. • to use the habitat map as baseline information on the location and extent of habitats. • to investigate the influence of changes in salinity and temperature on the reef. • to investigate how the Seacology dock has impacted the reef crest. • to assess coral reef growth rates.	• to evaluate the condition of coral reefs as development on the island increases. • to evaluate the impact of nitrogen and phosphorous on seagrass extent and coral reef condition. • to assess whether mercury from the mainland has influenced corals and fish.

6.4.1.4 Mapping Bunaken Island Using Satellite Imagery

Following discussions about map content, presentation, and applicability, many respondents asked about the satellite mapping process. Many were interested in how the map was created -- whether, for example, researchers had surveyed the habitats in the field to develop the classification. Other topics of interest included how the satellite could see so much detail on the ground from 600 km above the Earth, why the satellite could not image deeper than 30 m, and how the researchers programmed the satellite to fly over Bunaken Island. Additional queries are provided below.

> “When will the satellite fly over Bunaken Island again? We want to see how the seagrass is changing and we could do that with more and more satellite images. When will the satellite fly over the other islands in Bunaken National Park? Can you program the satellite to fly over the islands this summer?” BCCF Respondent.

> “We could use more high-spatial resolution images in our catalogue. How can we get this imagery? Who should we talk with?” UNSRAT and BNPMP Respondents.

These comments and questions led to discussions about imagery cost. At the time of this study, no stakeholder group was using satellite imagery for coral reef management. Imagery had been acquired for the Park in 2002; however, it was not in digital form, and the information from this study was not being used. In 2002, the Japan International Cooperation Agency (JICA) collected aerial photography of the Park; they also conducted a rapid assessment of terrestrial and marine habitat types. Although this information was greatly detailed and could potentially contribute to current and future management projects, it was not available in digital form, nor was the cost of the digital material within the financial means of the BNPMB or NGOs. Landsat imagery was available through Landsat.org; however, it cost $250 (USD) per image, and most respondents were not interested in paying for the satellite imagery.

> “We cannot afford an IKONOS image if it costs $4600 per image. That would pay everyone on the island for an entire year! We do not have that kind of money to buy an image, and then who would make the habitat map. Would we have to pay you to come back and make the habitat map?” BCCF Respondent.

> “We might be able to buy the cheaper imagery. But it is unlikely. We don’t know what to do with it after we buy it. We would need to hire a consultant to interpret it.” BNPMB Respondent.

> "We would like to add a copy of your imagery to our archive. Can you give us a copy of the imagery? We can use it in our classes and teach our students how to analyze the information. You could teach our students." UNSRAT Respondent.

> "There is a mapping team that has helped us create maps. They might know what to do with the imagery. We also have several people who are familiar with mapping processes in our office. I could give the imagery to them, and they could try to create other maps, though we cannot afford to buy this imagery; it is far too expensive." NRM III Respondent.

6.4.2 Focus Group Discussions

The presentation given to NRM III began enthusiastically. Attendees were excited about the spatial resolution of the habitat map and the ability to differentiate between habitat classes. Given that many attendees had been involved in habitat mapping projects, they were confident reading the map and interpreting meaning. The relevance of the IKONOS coral reef habitat map to current and future management projects, however, was described as 'loose', 'indirect', and 'irrelevant'. One respondent noted, "We have several maps that detail the location of habitats in more detail than your habitat map, and the fine-scale information is what we need to manage the marine resources." This comment initiated a number of subsequent contradictory comments that emphasized the value of the habitat map for managing specific resources such as seagrass and coral. Several respondents noted that seagrass was important to map to estimate changes in fish populations, while other respondents suggested mapping coral reef spatial extent to determine which zone had the greatest percent of living coral. Respondents believed that this type of information would fit into current management projects and provide a baseline from which coral health could be evaluated.

The presentation given to faculty members at UNSRAT (Mapping and Biology Departments) revealed a number of points of interest. First, when discussions focused on map content, members where impressed by the degree of spatial resolution offered by IKONOS imagery. However, they unanimously agreed that only species-level habitat maps were sufficient for management projects. Habitat maps with broad habitat classes such as coral, seagrass, and sand were inappropriate; they did not answer the important questions. Several members had been involved in a community-based mapping project and stated "… species level maps are critical for generating inventories of our marine resources. With this inventory we can demonstrate a high level of biodiversity, numerous indigenous species, and unique species that cannot be found anywhere else in the world. This brings attention to our marine resources and it brings funding to our department." Other members fully supported this comment. Regarding the cartographic representation of the mapped information, attendees agreed that it was appropriate for orientation. Several respondents noted that they found the map "clear" and "easy to read", though they would "benefit from having the dive sites or zones overlaid on the map" for reference. The applicability of the map to current management projects received less attention because of the amount of time members spent emphasizing the value of species-level information. However, two points of interest were discussed. One respondent put forth the idea of using the map to identify the loss of coral cover surrounding the dock on the northeastern coast of Bunaken Island. In 2002, efforts were undertaken to develop a dock that would both help prevent chronic damage to coral reefs and seagrass beds caused by boats anchoring in shallow waters, and allow access to the village when the tide is low. In 2004, the dock was completed. It is 595 feet long and has a small wooden structure on the end to act as a control point for park entrance fee collection and a community guard post. Attendees commented that construction of the dock had a destructive influence on the coral reefs in that area, and that sediment from the construction smothered nearby reefs. Therefore, there was interest in using the habitat map to investigate the change in living coral before and after dock construction. The second point of interest was put forth by a retired faculty member who suggested the use of multi-date imagery to assess the change in coral cover since the inception of the zonation plan. This comment initiated numerous responses from attendees. Comments suggested that attendees were highly interested in using a time series of images to assess changes in the environment because there had been no assessment of the marine resources since the inception of the zonation plan.

In Alung Banua village, members of the BCCF expressed their opinions and perspectives about map content, presentation, and applicability following a 30-minute presentation. When discussions began, members immediately focused on map applicability to recent management concerns. Because the zonation plan had been proposed as a tool to help maintain and potentially increase fish biomass, members were interested in learning whether the coastal environment had experienced this increase, particularly an increase in seagrass extent since the inception of the plan. One attendee stated “We see the large fishing boats arrive from the Philippines and they sit on the seagrass, where the fish live. They also catch the fish that live in the seagrass, and those are our fish. We worry about the seagrass and how it is being damaged!” In addition to seagrass extent, attendees also expressed an interest in using the map to identify the number of grouper and tuna habitats. Several attendees had recently participated in a grouper-monitoring workshop, and they were interested in monitoring these species as well as other commercially valuable species. One attendee noted, “The habitat map could identify the groupers and the tuna,” while a second attendee noted, “The habitat map could identify the grouper sites and show changes in the number of groupers.” It was evident from these comments that the cartographic representation of the data was inappropriate and misleading. The habitat classes confused attendees; homestays were mistaken for dive operations, coral and sand were mistaken for seagrass, and silt was not understood. In addition, small-scale presentation of the island created confusion and disorientation; it was difficult for attendees to orientate themselves to specific locations on the map that included the docks, government offices, markets, and homestays. As a result, a considerable amount of time was spent identifying these locations. And, once the locations were identified, several attendees commented that the map detail was insufficient to address current and future management projects.

In Manado, members of the North Sulawesi Watersports Association were also introduced to the habitat map, and most members were impressed with the degree of detail. The contents of the habitat map, however, did not elicit great enthusiasm; rather, a colour-composite of the image was of greater interest because of the potential to use this image in brochures, on the Internet, and in advertising campaigns. One respondent noted the potential value of a large wall-sized image of Bunaken Island that illustrated the location of dive sites and, beside each site, included photos of the types of species divers could expect to see. Following the discussion about map content, members discussed map use for selecting dive sites. One attendee noted that the habitat map would be useful for identifying new dive sites and for assessing the condition of coral at current dive sites. A second attendee commented on the use of the habitat map to identify sandy, flat, shallow areas (< 15m). Several dive operations provide diving courses that require the students and instructors to sit on the bottom and conduct safety drills. Because of the dramatically sloping seascape in most areas around the Island, there are few areas that provide a sandy, flat, shallow bottom. And those few are intensively used. One attendee noted "Sandy, shallow water areas are increasingly important because of the larger number of tourists who are visiting the island. Many days when I visit Fukui (a sandy, flat, shallow dive site) there are many boats there, and we have to change our plans. This is frustrating for our visitors." In light of attendees' strong focus on dive-site characteristics and conditions, the cartographic representation of the mapped information was clearly inappropriate. All attendees commented on the absence of the dive sites, and one noted, "You should have the dive sites on that map if you want to talk to dive operators." Other attendees unanimously agreed that it was important to include dive sites and zones on the map, and to remove the classification scheme. Another attendee noted, "I want to be able to see the coral, not a coloured area." Comments concerning the representation of the data were direct. For example, attendees noted that it was important to include the land, deep-water, dive sites, and zones in the map, and to avoid depicting coral and seagrass classes as polygons of different colours. The meeting ended following a brief discussion about the cost of the imagery. When the price was revealed to attendees, many immediately commented "This imagery is too expensive, we can't afford to use it for anything!" Several other attendees openly shared this view, although one noted, "… we could use one image over and over again." A brief discussion about the possibilities of a single image concluded the event.

Also in Manado, members of the BNPMP received a presentation on the habitat map. The presentation was brief to accommodate the time schedule, and, as a result, there was minimal time to discuss the habitat map. However, in the short time available, attendees focused on the potential use of the habitat map in assessing the condition of coastal resources. Board members noted that they had recently focused their efforts on developing monitoring programs and that the satellite imagery may provide assistance. The cartographic representation of the data, however, required considerable modification, according to the members. One Board member, who was particularly vocal, commented "We need to see the location of the zones, the dive sites, and the docks if we are to use this map. We need a colour-coded system to show improvement and damage in the zones." This member provided considerable advice both during and after the meeting by listing the type of information that would provide greater ease of map reading, and colours that would be most appropriate for identifying positive or negative changes in zonal condition. When attendees were asked which habitat types were of most value, one attendee noted “Seagrass is important, where the fish spend their time at night. We need to know how the seagrass has changed.” Several attendees commented that the habitats should be scientifically selected to “make the results valid.” Although the discussion was brief, the responses provided some knowledge of their perceptions of the habitat map and their thoughts about the use of the habitat map in management projects.

6.4.3 Participant Observation

At most meetings, a different topic was presented by a different attendee. The chair of the meeting always directed the proceedings and provided input irregularly throughout the proceedings, and always at the end. After a topic was presented, the group discussed it, and comments were made. All meetings were problem focused, and included discussions about the problem itself, who was involved, how long it has persisted, and where it is occurring. After these discussions were held, the chair of the meeting would ask if there were any other comments. If no comments ensued, the chair would ask if there were any solutions. At each meeting, following each problem, there were few, if any, solutions presented. Different topics were discussed in turn. At the end of the meeting, the chair would provide comments that summarized the discussion. Details of each meeting are provided below (Table 6.3).

Table 6.3. A summary of each meeting attended by the researcher.

Meeting	Chair	# of Attendees	Duration	Topics
NSWA	Elected Representative	17	2 hours 15 minutes	• Diver damage to reefs • Boat traffic at dive sites • Boats overloaded with tourists • Requirements for boat capacity • Dive guides and coral reef damage • Cost of boat fuel • Commonly visited dive sites
BCCF	Elected Representative	6	35 minutes	• Foreign fishing boats in coastal waters • Fishers and dive site conflicts • Boat traffic around Pangalisang Dock • Boat use of Seacology Dock
BNPMB	Representative from the Ministry of Tourism	9	1 hour 45 minutes	• Visitors to Bunaken Island • Collection of fees • Tag competition • Fishers use of zones • Scholarships for students • Boat traffic at Pangalisang Dock

Few solutions had been arrived at by the end of each meeting. However, this was to be expected. These meetings exemplified the 'socialization' process inherent in local decision-making. Socialization is the process of communicating the idea/problem to all present until there is full agreement about the problem. Only after such agreement can solutions be developed, and the solutions will require that the same process be completed, as does the strategy to implement the solution. Therefore, a considerable amount of time must be invested in the process.

There were several noteworthy differences between the three meetings. At the NSWA meeting, dive operators came to an agreement on two solutions for two current problems. The first problem was that the number of people per dive boat has been steadily increasing, resulting in an increase in the number of divers at one time at a dive site. With more divers in the water, more damage has been done to the reefs. NSWA members wanted to restrict the number of divers per boat. They unanimously agreed that no more than 8 divers should be permitted on one boat at a time. The second problem was that several dive guides have been breaking coral by sitting or standing on stands of branching coral, a practice that upsets many tourists. However, identifying the dive guide is impossible underwater. NSWA members agreed that all dive guides must have their names written on their mask strap to permit identification. Potential reasons that these decisions were reached so quickly include (1) the majority of dive operators follow a democratic voting process to make decisions, (2) NSWA members meet infrequently, so there is urgency to address problems when they are discussed, and (3) NSWA was originally set up to address problems quickly, as decisions in favour of tourist requests are directly related to dive operator income.

At the BCCF meeting, problems concerning boat traffic were discussed; however, no solutions were proposed. The chair of the meeting noted that he would discuss the issues with members of NRM III. From NRM III, he would seek solutions and then present them to the group at a later date. All of the attendees agreed that this was the most appropriate course of action. In general, the meeting involved lengthy discussions, and the topics were socialized to the group.

At the BNPMB meeting, problems concerning a number of different issues were discussed. Although most attendees did not present solutions, the chair of the meeting suggested several ideas. The chair suggested that those in attendance should consider the ideas, and prepare responses to them for the next meeting. The chair provided direction both during and at the end of the meeting. During the meeting, if the chair felt that a comment was not relevant to the topic, he would cut into the comment and remind attendees that they should be speaking directly to the issue. At the end of the meeting, it was the chair who summarized comments made, presented solutions, and directed attendees on their next duties. One reason for this seemingly regimented process is that the chair is a member of the Ministry of Tourism who is used to a regimented schedule in his own office. The meeting followed a schedule that had been distributed to attendees, and ended when the schedule indicated the meeting would end. Questions were raised at the end; however, they were not addressed because the chair indicated that a time slot for questions had not been included on the schedule. It was obvious that the chair's expectations and attendees expectations of the meeting and decision making process conflicted. Several attendees commented on their frustrations about these processes following the meeting.

6.5 EVALUATION OF THE RESEARCH

In this chapter, a method for investigating stakeholder receptivity to the 2001 habitat map is proposed. According to Freire (1970), an individual's receptivity is a function of the social and physical environment in which he or she lives. In the context of this research, stakeholders' receptivity to the habitat map reflects their awareness and understanding of what is important in the realm of coral reef management and what approaches and methods are socially acceptable. The method presented here is, to the best of the researcher's knowledge, the first investigation of its kind that actively explores stakeholder receptivity to a coral reef remotely-sensed habitat map.

6.5.1 Strengths

- The study presents a clear and logical structure that permitted the researcher to categorize the field data and to learn and understand multiple processes. The methods selected for this study were straightforward and easily understood by respondents and stakeholder groups.
- Permission to present at meetings and access to closed discussions was a considerable benefit to this study. In addition, respondents were willing to participate in interviews and felt comfortable providing their opinions. One reason for this is that Bunaken Island has been the target of numerous quantitative and qualitative studies, so interviews and the interview process are familiar to many stakeholders.
- Multiple visits to Bunaken Island demonstrated to respondents and stakeholders that the researcher had a vested interest in the community. Therefore, it was common for the researcher to be invited to participate in local activities and celebrations, from which casual conversations could be held.

6.5.2 Weaknesses

- The strength of this study is only as good as the translation of the information. Although the researcher had taken language training in Yogyakarta and was comfortably fluent, respondents and stakeholders used a dialect different in terminology from the national language. Therefore, a great deal of assistance was required from the NRM III assistant and other members who were personally connected to the issues. Therefore, it is likely that some of the information was translated in a different context.

- The researcher's interpretation of the qualitative data might not have been correct when identifying the major themes or when identifying the lessons learned. Possible causes of bias or error in interpretation include cultural differences, language constraints, lack of objectivity, and closer associations with certain individuals.

6.5.3 Considerations for Strategy Development

Several noteworthy findings from this study will be used as inputs in the following chapter (Chapter Seven). These findings have been divided into the following categories: map content, map presentation, and map applicability.

6.5.3.1 Map Content

1. A habitat map should contain no more than 3 to 4 marine habitats that are directly relevant to the current and future management projects. It is unlikely that the map will be used if any feature is indirectly correlated to the project.
2. A coral reef habitat map should contain only those habitats that are relevant to each stakeholder group.
3. Habitats should be described using local names to ensure effective communication.

6.5.3.2 Map Presentation

1. A habitat map should include land, deep water, and local markers such as docks, villages, churches, mosques, markets, homestays, and roads. Most importantly, the location of dive sites and each zone should appear on habitat maps, regardless of the stakeholder group for which the map is intended. When the habitat map is intended for a specific stakeholder group, the specific orientation features (section 6.4.1.2) should be used as a guide.
2. A habitat map should include standard cartographic elements such as a north arrow, scale, title, legend, and brief description about the imagery. The map-maker and his/her contact information should also be provided.

3. Habitat maps should mirror the style of the local maps used by the stakeholder group for which the map is intended. It is highly recommended that local maps be acquired and used as a template when creating the habitat map.

6.5.3.3 Map Applicability

1. Applicability of a habitat map is highly dependent on the identification of local linkages drawn between habitat and current and future management projects. For example, members of BCCF commented that the spatial extent of seagrass was directly linked to the available stock of several commercially valuable fish. Therefore, the spatial extent of seagrass can be mapped to communicate information about stocks.
2. Coral reef features identified in the habitat map should be discussed with stakeholders to clarify how the habitat within a remotely-sensed image is defined.
3. Map applicability is likely to increase if the map is created and designed for a specific stakeholder group.

6.5.4 Conclusions and Future Research

The focus of this research has been to investigate stakeholder receptivity to the coral reef habitat map. In the next chapter, how linkages can be formed between habitats and management project objectives is investigated, and the results of this investigation are used in the subsequent stage. This chapter concludes the second step in the four-step strategy that seeks to guide the use of remotely-sensed information in coral reef management for Bunaken Island, Indonesia.

CHAPTER SEVEN:
LINKING CORAL REEF MANAGEMENT PROJECTS WITH REMOTELY-SENSED HABITAT DATA

SUMMARY

In this chapter, a process that links coral reef management projects, identified by stakeholders (Chapter Six), with remotely-sensed coral reef habitat data (Chapter Five) is demonstrated. The process involves deconstructing each project to identify indicator(s), the spatial location and extent of each indicator(s), and the time period of interest, and then identifying habitat data that most closely represent each indicator(s) and the spatial and temporal characteristics. Results from this process are used to calculate a "degree of association" that defines the strength of association between indicator(s) and habitat(s). Results suggest that most indicators, including their spatial and temporal characteristics, can be represented by habitat data, and that 66% of the indicator(s) have a strong degree of association with the habitat data. This suggests that coarse habitat data, delineated in satellite imagery, are appropriate for addressing coral reef management projects.

7.1 STUDY AREA

In this section, the physical and social environments in which the research took place are described. This research focuses on the coral reef environment that surrounds Bunaken Island: the coral reefs are located within the boundaries of Bunaken National Park (N 1^{o} 35' - 1^{o} 49'; E 124^{o} 39' - 124^{o} 35'), North Sulawesi, Indonesia. The coral reef environment includes three geomorphological zones (reef flat, reef crest, and reef slope), and throughout these zones are numerous habitat types including, but not limited to, coral, seagrass, sand, silt, rubble, and hard rock (Erdmann *et al.*, 2004; Newman *et al.*, 2007). These habitat types are common to most Pacific- and Atlantic-based coral reef ecosystems (Birkeland, 1997; Veron 2000), whereas the habitat types specific to Bunaken Island include boulders (3-5 m in diameter), lagoons (3-5 m deep), and silt-covered coral. For a detailed description of the major habitat types of Bunaken Island, see Chapter Five.

This research also focuses on the coral reef management interests of stakeholder groups of Bunaken Island. All seven stakeholder groups were identified for this research. The primary stakeholder groups include the North Sulawesi Watersports Association (NSWA) and the Bunaken Concerned Citizens Forum (BCCF). Within the municipality of Manado, these two groups are officially recognized as 'dominant' stakeholder groups as they are directly connected to the health and status of marine resources; they are the most intensive and extensive users of the marine environment, and they are directly affected by changes in the coral reef environment. The secondary stakeholder groups include the Ministry of Tourism, Bunaken National Park Management Board (BNPMB), Scream (local NGO), Natural Resources Management (NRM III), and Universitas Sam Ratulangi (UNSRAT – Mapping Department). BNPMB is comprised of a collection of representatives from the other stakeholder groups (NSWA, BCCF, Ministry of Tourism, NGO). Secondary stakeholder groups contain representatives who have a stake or interest in the management of Bunaken Island's coral reefs, and who may or may not directly depend on the health and condition of the coral reef resource. A more detailed description of each stakeholder group is provided in Chapter Four.

In this chapter, the coral reef management projects of both primary and secondary stakeholder groups are targeted. In 2001, stakeholder groups regarded the coral reef zonation plan (Figure 7.1) with both great interest and skepticism. The plan was put in place to reduce resource conflict between dive operators and fishers by demarcating the primary values of the park through the use of a zoning system, which identified explicit rules for each zone. This plan was the first formal approach to coral reef management, and, as a result, was the catalyst for numerous related management projects. Data collection for this research corresponded with the implementation of the coral reef zonation plan, and, as a result, the coral reef management projects collected (Chapter Six) and processed in this chapter concern the zonation plan in some capacity.

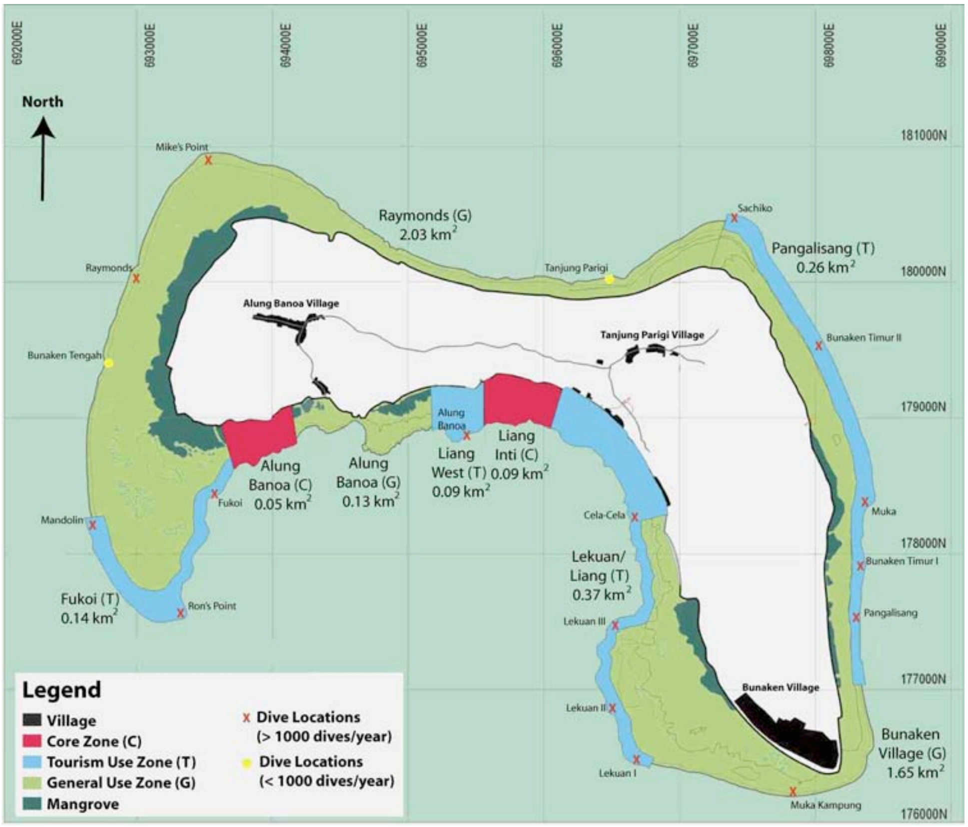

Figure 7.1. Zonation plan for Bunaken Island with core, tourism use, and general use zones, and the location of dive sites.

7.2 METHODS AND MATERIALS

7.2.1 Quantitative Data

The quantitative data in this research includes the 2001 and 2004 coral reef habitat maps of Bunaken Island. Delineated habitats include: coral (<5 m deep), coral (5-15 m deep), seagrass, silt, and sand, and lagoon (Figures 7.2 and 7.3). All features residing within the terrestrial environment were removed from the image. Mapping accuracy was determined to be 75% and 81% repsectively, while the habitats were delineated with a high level of confidence (ROI separability > 1.8). The delineated habitats reflect dominant habitat types that have been identified in coral reef remote-sensing studies that use IKONOS satellite imagery (Andrefouet, 2006; Green *et al.* 2000; Mumby *et al.* 2002). For a complete description of the procedure that was used to generate the habitat maps, see Chapter Five.

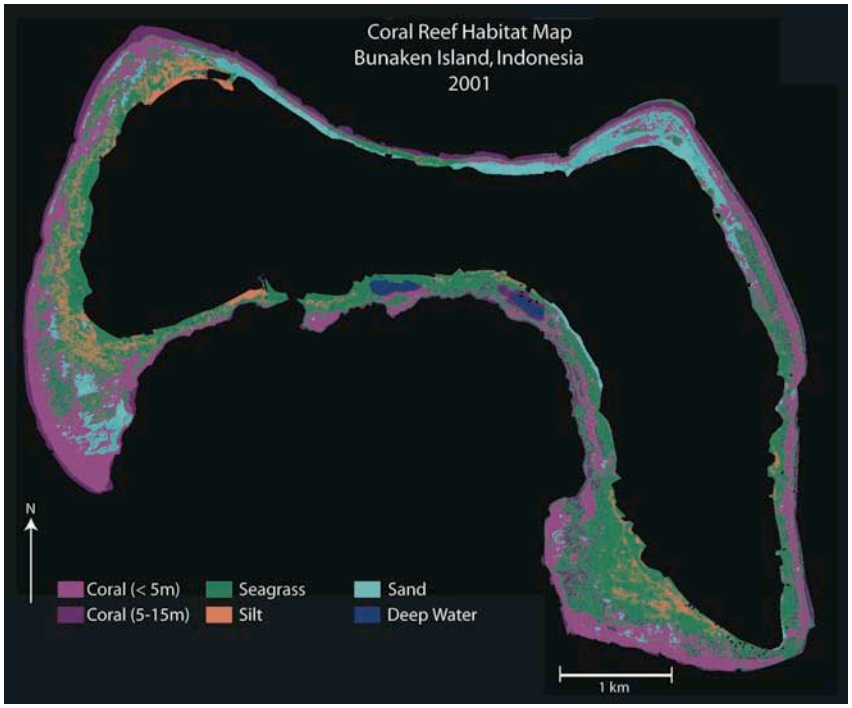

Figure 7.2. Habitat map of the coral reef environment surrounding Bunaken Island (2001). Land and deep water (> 30 m deep) have been removed.

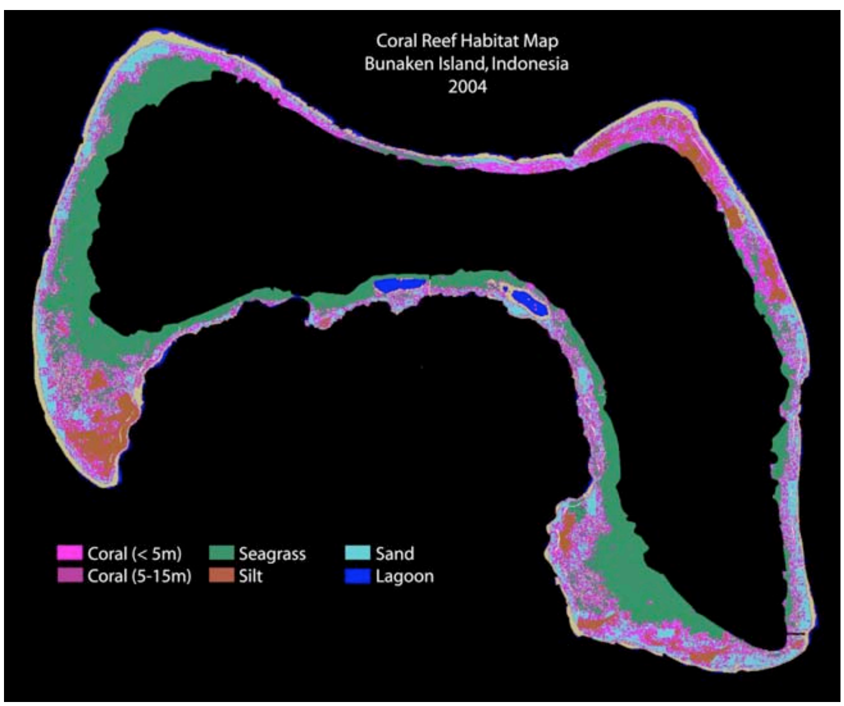

Figure 7.3. Habitat map of the coral reef environment surrounding Bunaken Island (2004), including the reef flat, reef crest, and reef slope. Land and deep water (> 30m) have been removed.

7.2.2 Qualitative Data

The qualitative data includes stakeholder responses to habitat map applicability to both current and future coral reef management projects. In 2004, during the months of May through June, informal interviews and focus group discussions were held on Bunaken Island and in the city of Manado and ranged in duration from 30 to 60 minutes. In total, 36 stakeholder respondents were interviewed and five presentations were made to different stakeholder groups. Stakeholder respondents belong to one or more of the following groups: North Sulawesi Watersports Association (NSWA), Bunaken Concerned Citizens Forum (BCCF), Ministry of Tourism (MofT), Bunaken National Park Management Board (BNPMB), Scream, Natural Resources Management III (NRM III), and UNSRAT (Universitas Sam Ratulangi). A summary of the responses, identified through informal interviews and focus group discussions, were provided in Table 6.2, though are repeated here to ease reading (Table 7.1).

Table 7.1. Suggested applications of the habitat map to coral reef management project objectives by stakeholder groups.

Stakeholder Group	Current Management Project Objectives	Future Management Project Objectives
North Sulawesi Watersports Association (NSWA)	• To investigate the quality of the dive sites. • To identify changes in dive site quality since inception of the zonation plan. • To identify areas that are suitable for OPEN Water dive courses • To investigate the impact of boat traffic on dive sites. • To investigate the condition of dive sites nearby Bunaken Village.	• Investigate coral reef deterioration rates at dive sites. • To identify changes in boat channel size since the inception of the zonation plan. • To identify areas that are suitable for boat channels nearby dive resorts.

Continued from Table 7.1.

Bunaken Concerned Citizens Forum (BCCF)	• To investigate changes in seagrass. • To identify the seascape condition in which medicinal organisms can be found. • To investigate changes in sea level. • To identify the impact of divers on coral reefs. • To identify the status of fish stocks.	• To identify existing reef fish movements between management zones. • To identify changes in reef fish populations since the inception of the zonation plan. • To assess grouper populations in all zones.
Ministry of Tourism (MofT)	• To identify the overall condition of the coral reef environment. • To compare the impact of divers on coral reefs between each dive site. • To assess the change in coral reef condition between years of high and low visitor numbers. • To identify boat impacts on coral condition. • To identify hotspots of biodiversity.	• To identify the impact of fishing nets on coral reefs. • To identify the impact of blast fishing on coral reefs. • To identify changes in reef flat conditions since the inception of the zonation plan.
Bunaken National Park Management Board (BNPMB)	• To investigate coral condition in each zone. • To evaluate the effectiveness of the zonation plan. • To identify zones with the poorest coral reef condition. • To identify the impact of garbage from Manado on the reefs. • To identify changes in the grouper monitoring sites.	• To identify the impact of rapidly changing water temperatures on coral condition. • To identify the impact of refuse from the island on coral condition. • To assess changes in fish migration patterns.
Scream	• To identify the number of boat scars throughout the reef. • To identify the impact of foreign fishing vessels on the reef.	• To identify the rate of larvae loss from the coral reef ecosystem. • To identify the impact of dust on coral condition.

Continued from Table 7.1.

Natural Resources Management III (NRM III)	• To compare coral condition at sites with high and low boat traffic. • To investigate the progress of existing eco-reefs. • To investigate the impact of runoff on coral condition. • To identify changes in coral condition at the northwestern corner. • To compare the condition of coral in front of Bunaken and Alung Banoa Villages.	• develop a standard baseline habitat map for stakeholders. • To develop a zonation/habitat map to assist patrols with enforcement. • To assess the impact of boat traffic on coral condition at both docks.
Universitas Sam Ratulangi (UNSRAT)	• To identify the location of species at risk. • To investigate the impact of salinity and temperature changes on the reef. • To investigate the impact of the Seacology dock on coral biodiversity. • To investigate coral reef growth rates. • To investigate the impact of nitrogen and phosphorous on seagrass.	• To assess changes in coral cover as coastal development increase. • To identify the impact of mercury on coral and fish health. • To identify areas of larvae sources and sinks.

7.3 DATA PROCESSING

Current management project objectives were isolated for data processing, and for each objective three elements were identified: indicator(s), the spatial location and extent of each indicator, and the time period of interest. An indicator(s) is defined as a biophysical feature(s) within the coral reef environment that stakeholders identified as the ‘feature of interest’. Examples include coral health, fish biodiversity, and seagrass coverage. Spatial location and extent are described in terms of geomorphological and management zones, while the time period of interest is described in years. While compiling the data it became evident that several indicator(s) were not clearly defined. For example, several BCCF respondents stated that they were concerned about the populations of fish populations, however, the specific species of fish, habitat, and feeding patterns were not indicated. As a result, the researcher could not identify the specific habitat of interest to the stakeholder group. The researcher addressed this problem by revisiting respondents and asking for clarification. By the end of this process, only two stakeholders could not be reached, and, as a result, their objectives were excluded from analysis. Beyond clarifying 'feature(s) of interest', the most challenging element to address was the spatial location and extent of an indicator, as respondents then used terms and phrases unfamiliar to the researcher. To address this, the researcher participated in excursions with respondents to collect GPS measurements at or around the feature(s) of interest. For example, to identify the spatial location and extent of dive sites, the researcher participated in several dive trips and collected GPS measurements at the start and end of a dive and made notes during the dive about the position of divers relative to the geomorphological and management zone boundaries. When GPS measurements could not be collected, respondents were asked to identify the spatial location and extent of the feature on a colour-composite satellite image of Bunaken Island. The 2004 IKONOS satellite image was used for this process.

Next, indicator information was translated to habitat data from the 2001 habitat map, including both spatial and temporal scales (Figure 7.4). Translation from indicator to habitat was conducted with assistance from three NRM III personnel: two biologists and one cartographer. Discussions were held over a 2-week period, and resulted in the selection of a habitat (2001 habitat map) that could directly or indirectly represent the indicator, and identification of whether the spatial and temporal characteristics of the indicator could be linked to the spatial and temporal characteristics of the selected habitat. Next, a decision key was used to determine the strength of association between the indicator and indicator characteristics and the habitat and habitat characteristics. The decision key is described in the following section.

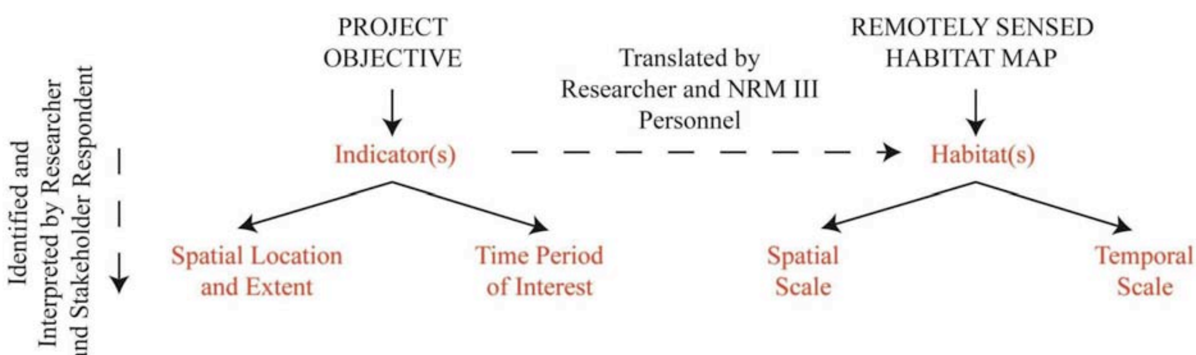

Figure 7.4. A summary of the information identified for each project objective (red).

7.3.1 Degree of Association

To determine the strength of association between indicator(s) and habitat(s), a decision key was developed (Figure 7.5). Satellite-imagery-selection decision keys developed by remote sensing scientists (Phinn *et al.*, 2000b, Green *et al.*, 2000) were used to guide the development of the degree of association decision key. The premise is that an indicator with biophysical properties and known spatial and temporal characteristics can be linked directly or indirectly to a habitat type (2001 habitat map). When an indicator, such as coral health, can be directly linked to a habitat type, such as live coral cover at relevant spatial and temporal scales, the association between indicator and habitat is 'strong'. As fewer characteristics are linked, the strength of the association decreases. Within the decision key, strength is classified into four separate categorizes: strong, moderate, weak, and none. For each objective, the strength of association between indicator and habitat was calculated.

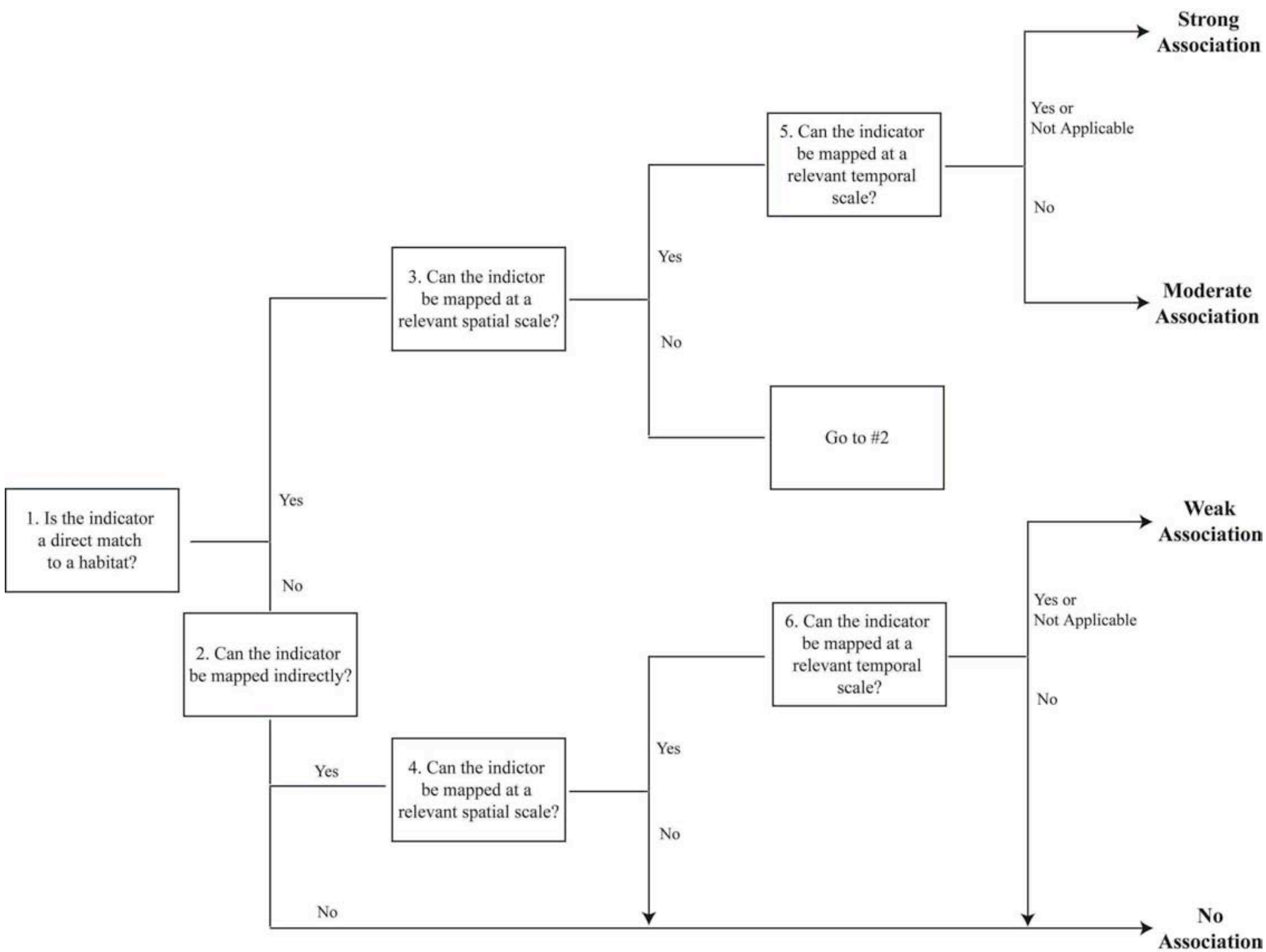

Figure 7.5. Degree of Association decision key.

7.4 RESULTS

For each project objective, an indicator(s), spatial location and extent, and time period of interest, were identified. Next, habitat data and associated spatial and temporal scales were matched to the indicator(s) (Figure 7.6). For most project objectives, the researcher and NRM III personnel identified direct links between habitat(s) and indicator(s). A direct link occurs when a habitat accurately represents an indicator. For example, coral cover (indicator), as identified by a NSWA respondent and meant to represent 'living coral', can be directly linked to coral cover (habitat), a habitat type identified in the 2001 remotely-sensed habitat map. An indirect link occurs when an indicator can be linked through a secondary association. For example, biodiversity (indicator), as identified by a BCCF respondent and meant to represent the number of fish, is indirectly linked to seagrass (habitat), a habitat type identified in the 2001 remotely-sensed habitat map. Seagrass can be used, albeit indirectly, to identify the location of nursery and breeding grounds; however, seagrass cannot be used to directly represent fish biodiversity. A direct indicator would include coral rugosity, calculated as the ratio between the contour-following distance between two points on the reef and the distance between the same two points as measured in a straight line (Risk, 1972), and which has been shown to influence fish biodiversity (Knudby *et al.*, 2007); however, rugosity is not a habitat type within the 2001 habitat map. During several translation (indicator to habitat) discussions, the researcher and NRM III personnel sometimes disagreed on the selection of habitats. To address this issue, a vote was held. Descriptions about the project objectives, indicators, and habitats for each stakeholder group are provided below.

7.4.1 North Sulawesi Watersports Association

The projects proposed by the NSWA respondents focused mostly on the quality of, change to, and impact on, dive sites. NSWA respondents expressed concern about dive site conditions, specifically how the loss of coral cover will negatively impact diver experience.

> "If a dive site deteriorates we are forced to use other dive sites. This means that the other dive operators are also forced to use other dive sites, creating congestion at these sites. Divers don't like to see other divers while underwater, they want to see coral and big fish. Too many divers at one site scare the fish away, and this changes a

divers' underwater experience. We want our guests [divers] to have a great experience with us. We want them to come back year after year!"

In addition to dive site condition, NSWA respondents also proposed the use of the habitat map for identification of areas suitable to conduct the field component of the Open Water (PADI) dive course. Respondents noted an increase in the number of tourists they were receiving each year, and a corresponding increase in diving certification interest.

"Tourists not only want to dive, they also want to get their diving certifications, specifically the Open Water Diving Certification. Our dive operation is certified through PADI, and we are authorized to provide Open Water, Advanced Open Water, Rescue Diver, and Master Certification. The problem is we don't have a suitable dive site for students. Most dive sites have a reef crest that is full of coral, followed by a very steep drop-off. We definitely can't take our beginner students to these locations."

A suitable dive site in this context is defined as a shallow (< 15 m deep), sandy, low relief bottom, and located nearby the dive operation. Respondents indicated that, in the event of an emergency, immediate access to their dive operation is crucial, especially while conducting an introductory diving course. Because dive sites are a main focus of several project objectives, the researcher explored the spatial location and extent of these sites initially by locating and reviewing dive maps. Findings suggested that the location of dive sites varies considerably and that dive sites are recognized as a single point on the map (Figures 7.6 - 7.10).

Figure 7.6. Two Fish Divers dive site map illustrating the starting point of dive sites within the northern section of Bunaken National Park.

Figure 7.7. Bastianos dive site map illustrating the starting point of dive sites within the northern and southern sections of Bunaken National Park.

Figure 7.8. Froggies dive site map illustrating the starting point of dive sites within the northern section of Bunaken National Park.

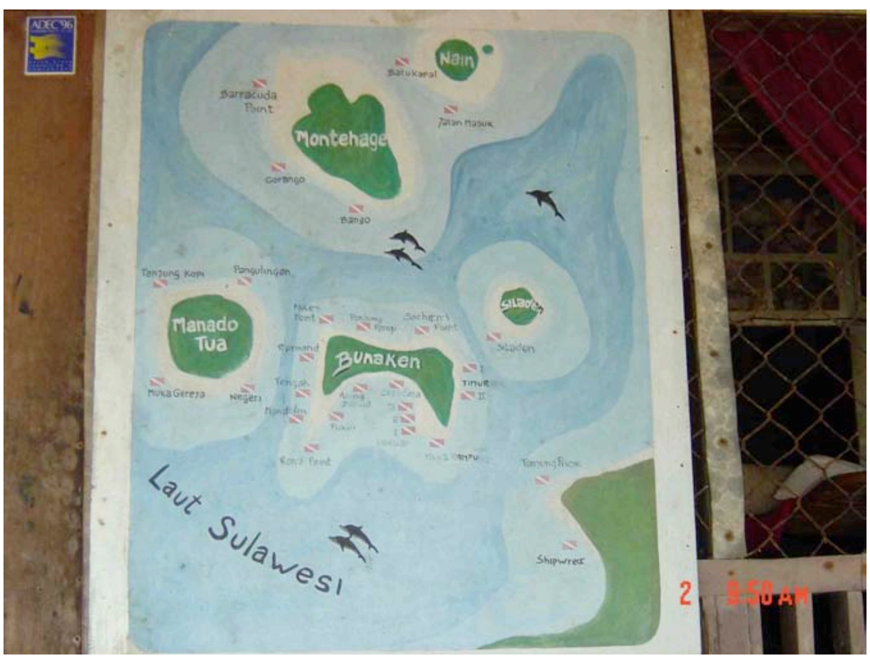

Figure 7.9. Unknown dive site map illustrating the starting point of dive sites within the northern and southern sections of Bunaken National Park.

Figure 7.10. SDQ dive site map illustrating the starting point of dive sites within the northern section of Bunaken National Park.

Using these dive site maps as a guide, the location of each site was calculated and illustrated on the Bunaken Island zonation map. In addition, dive sites were categorized into two categories: dive locations with more than 1000 dives/year and dive locations with fewer than 1000 dives/year, as identified in a study by DeVantier and Turak (2004) (Figure 7.11).

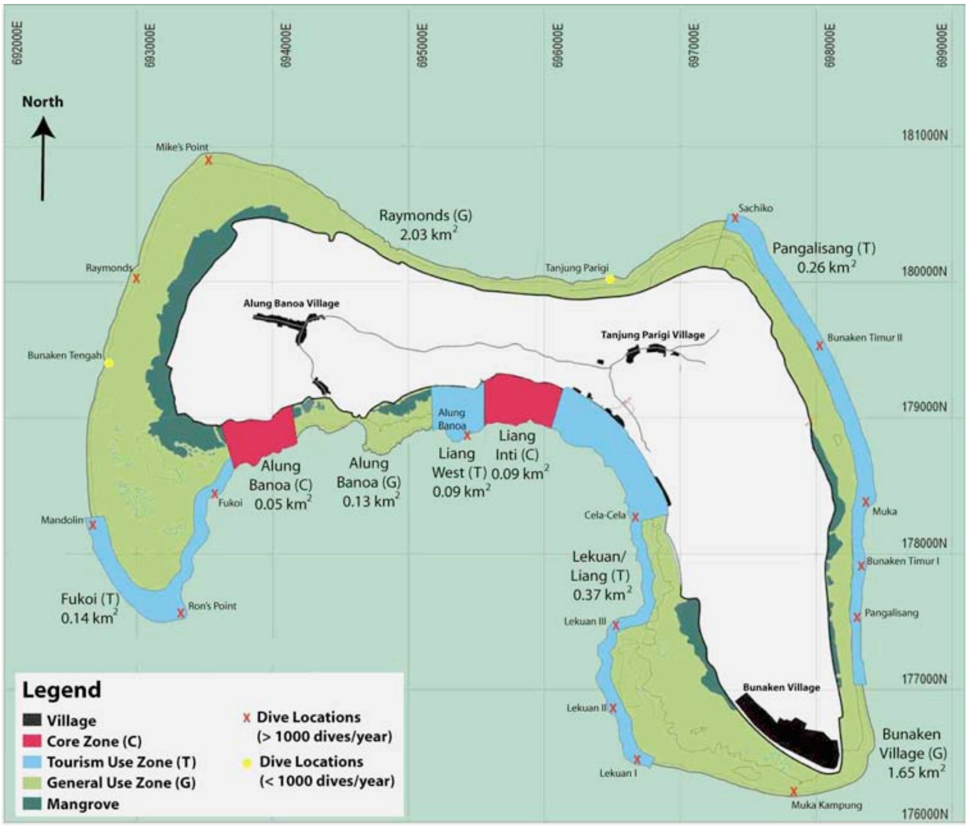

Figure 7.11. Overlay of dive sites on the Bunaken Island Zonation Map.

The spatial extent of each dive, however, was not available or identified in any dive operation maps. Spatial extent refers to the area in which divers spend the full extent of the dive. Divers spend most of a dive in transit; therefore, point data does not capture dive extent. To identify dive site extent, NSWA respondents were asked to identify in which geomorphological zone divers spend most of the dive, which direction divers travel, and how far divers travel along the reef crest. Responses were mixed and uncertain. To address this uncertainty, the researcher participated in several dive expeditions with four different NSWA dive operations. To map the spatial extent of each dive site, GPS measurements were recorded at the start and end of each dive, and notes about the diver's position relative to the reef flat, crest, and slope were taken during the dive. Results indicated that divers start and end a dive above the reef crest, while the majority of the dive is spent alongside the reef slope, traveling in the direction, and, at the speed, of the prevailing current. Results also indicated that the current directly influences the size and shape of the spatial extent of a dive. During most expeditions, divers are told to travel with the current, as traveling against the current results in faster air consumption and shortens the length of the dive. At some dive sites, such as Alung Banoa and Lekuan III, the direction of diver movement is mainly west and south, respectively, and includes the full extent of a coral outcrop. At other dive sites, such as Lekuan II and Fukoi, the direction of diver movement varies because current movement varies daily at these locations, thereby changing the spatial extent. At Pangalisang and Bunaken Timur I dive sites, the spatial extent of each site overlaps. The starting point of each dive, however, remains constant from day-to-day and between dive operators. These starting points are identified by a mooring buoy at Fukoi and Lekuan II, and by boat drivers who calibrate the position of the boat by aligning a point on land and a point in the water. Spatial extent of each dive site is identified in Figure 7.12, which includes the direction of diver movement, as experienced by the researcher and noted as the 'regular' direction of movement by respondents.

Figure 7.12. The spatial location and extent of dive sites surrounding Bunaken Island. An 'x' represents the starting point of a dive, the arrow represents the typical direction of the dive, and the box represents the spatial extent of the dive site.

Indicator(s) and habitat(s) data are noted in Table 7.2. Concerning the indicator(s) data, some respondents identified numerous indicators, after which they were asked to select 1-2 indicators that best represented the 'feature(s) of interest'. Answers were recorded, and details were requested, to assist with translation of indicator(s) to habitat(s) data. Then, habitat(s) from the 2001 habitat map were matched to the indicator(s). For example, coral (habitat) was matched to live coral cover (indicator). Next, whether the spatial and time period characteristics could be addressed using the spatial characteristics of the habitat and 2001 and 2004 habitat maps are identified.

Table 7.2. Results of the interpretation of project objectives and the translation of project objectives to habitat information available via the 2001 habitat map. Shaded columns represent elements translated by the researcher and NRM III personnel.

NSWA	**Objective**	**Spatial Location and Extent** (Geomorph and Management Zones)	**Indicator(s)**	**Time Period of Interest**	**Habitat(s)**	**Spatial Scale**	**Temporal Scale**
1	To investigate the quality of the dive sites.	Dive sites within tourism zones.	Coral cover.		Coral (< 5m) Coral (5-15 m)	Yes	
2	To identify changes in dive site quality since inception of the zonation plan.	Dive sites within tourism zones.	Increase or decrease in coral cover and reef fish.	2001 and 2004	Coral (< 5m) Coral (5-15 m)	Yes	Yes
3	To identify areas that are suitable for OPEN Water dive courses.	Reef flat within the tourism zones.	Depth < 15 m Sandy bottom Flat seascape		Silt Sand	Yes	
4	To investigate the impact of boat traffic on dive sites.	Reef crest within tourism zones.	Presence of boat scars Presence of net dragging		Coral (< 5m)	Yes	
5	To investigate the condition of dive sites nearby Bunaken Village.	Reef crest and slope at Muka Kampung dive sites.	Coral cover. Presence of boat scars.		Coral (< 5m) Coral (5-15 m)	Yes	

7.4.2 Bunaken Concerned Citizens Forum

BCCF respondents proposed many projects, and after the responses were compiled, projects focused on 5 main objectives:

- To investigate changes in seagrass.
- To identify the seascape condition in which medicinal organisms can be found.
- To investigate changes in sea level.
- To identify the impact of divers on the coral reef.
- To identify the status of reef fish stocks.

Most respondents identified a critical need to investigate changes in seagrass because a loss in the spatial extent of seagrass translates to a loss in the available area for small fish to acquire shelter from predators or during spawning periods.

> "If the seagrass deteriorates, where will the fish go to spawn? They will not have an area for shelter, for growth, or for reproduction. We are concerned that boat traffic impacts the seagrass, destroys it, and it will never grow back. We want to know how big the seagrass area is now, so we can protect it."

Along a similar theme, BCCF respondents were concerned about the status of reef fish stocks. These fish can be sold in the local market, and respondents can acquire a sufficient financial return – providing food for themselves and families for several days. A decline in reef fish stocks, therefore, would translate to a significant negative impact, challenging existing subsistence practices.

> "We don't know what we would do if we could no longer catch reef fish. They provide food for my family. I can buy three bags of rice, and that supports my family for days. I want to know about the stock. Is it in good condition? If not, we must do something immediately. Can your map tell us about the stock?"

A summary of the projects proposed by BCCF respondents is provided in Table 7.3. The table includes the following headings: Project Objective, Geomorphological and

Management Zones, Indicator(s), Related Habitat(s), Temporal Scale (where applicable), and Temporal Scale (if available). Concerning the Geomorphological and Management Zones, respondents were asked to identify the spatial location and extent of the feature of interest that included seagrass, seascape, shoreline, coral reef, and approximate location of fish stocks. Similar to the field data collection method utilized to confirm the spatial location of dive sites with NSWA respondents, field data were collected for the features identified above by accompanying respondents to each site. GPS measurements were recorded continuously at the feature of interest. This same process was conducted for the remaining stakeholder groups.

Table 7.3. Results of the interpretation of project objectives and the translation of project objectives to habitat information available via the 2001 habitat map. Shaded columns represent elements translated by the researcher and NRM III personnel.

BCCF	**Objective**	**Spatial Location and Extent** (Geomorph and Management Zones)	**Indicator(s)**	**Time Period of Interest**	**Habitat(s)**	**Spatial Scale**	**Temporal Scale**
1	To investigate changes in seagrass.	Seagrass within the tidal flat.	Increase or decrease in seagrass spatial extent between 2001 and 2004.	2001 and 2004	Seagrass	Yes	Yes
2	To identify the seascape condition in which medicinal organisms can be found.	Tidal flat in all zones.	Increase or decrease in habitat connectivity.		Coral (< 5m) Seagrass	Yes	
3	To investigate changes in sea level.	Shoreline.	Increase or decrease in sea level.	1990 and 2004	Silt	Yes	No (2004 only)
4	To identify the impact of divers on the coral reef.	Dive sites within the tourism zones.	Coral cover.		Coral (< 5m) Coral (5-15 m)	Yes	

5	To identify the status of fish stocks.	Reef crest in all zones.	Increase or decrease in reef fish.		Coral (< 5m) Coral (5-15 m)	Yes	

7.4.3 Ministry of Tourism

Projects proposed by Ministry of Tourism respondents focused on three areas that included coral condition, fish stock, and biodiversity. Respondents were interested in these areas because a negative change in any of these features "… would result in a change in tourism numbers." The five primary objectives included:

- To identify the overall condition of the coral reef environment.
- To compare the impact of divers on coral reefs between each dive site.
- To assess the change in coral reef condition between years of high and low visitor numbers.
- To identify boat impacts on coral condition.
- To identify areas of high coral and fish biodiversity.

Most respondents noted, first, a need to identify the overall condition of the coral reef environment because modified marketing and advertising campaigns in 2004 utilized statements such as "best coral environment" and "high quality corals" and "best diving conditions" to describe coral reef condition surrounding Bunaken Island. Ministry respondents wanted to ensure that these statements would not be proven false. In addition, they were interested in illustrating 'high quality corals' through the use of a satellite image. As one respondent noted, "Your satellite image would help us illustrate the point: We [Bunaken Island] have [has] the best coral reefs in the Pacific!" The interest in identifying the condition of the coral reef environment parallels an interest in identifying hotspots of biodiversity. Respondents stated that hotspots of biodiversity are important on an international level, and, therefore, should be identified for Bunaken Island and, then, marketed to the IUCN, to NOAA, and to the World Bank. As one respondent noted, "Hotspots of biodiversity will bring greater attention to Bunaken. This means more tourists!" The remaining interests were identified within a theme of increasing tourism numbers: identifying areas of impacted coral and guiding tourists elsewhere. A summary of Ministry of Tourism interests is presented in Table 7.4.

Table 7.4. Results of the interpretation of project objectives and the translation of project objectives to habitat information available via the 2001 habitat map. Shaded columns represent elements translated by the researcher and NRM III personnel.

MofT	Objective	Spatial Location and Extent (Geomorph and Management Zones)	Indicator(s)	Time Period of Interest	Habitat(s)	Spatial Scale	Temporal Scale
1	To identify the overall condition of the coral reef environment.	Reef crest and reef slope in all zones.	Coral cover.		Coral (< 5m) Coral (5-15 m)	Yes	
2	To compare the impact of divers on coral reefs between each dive site.	Dive sites within all management zones.	Coral cover.		Coral (< 5m) Coral (5-15 m)	Yes	
3	To assess the change in coral reef condition between years of high and low visitor numbers.	Reef crest and reef slope at dive sites.	Coral cover.	2001, 2002, 2003, 2004	Coral (< 5m) Coral (5-15 m)	Yes	2001 and 2004 only
4	To identify boat impacts on coral condition.	Reef crest.	Coral cover.	2001, 2002, 2003, 2004	Coral (< 5m)	Yes	2001 and 2004 only
5	To identify hotspots of biodiversity.	Reef flat, crest, and slope.	Coral biodiversity.		Coral (< 5m) Coral (5-15 m)	Yes	

7.4.4 Bunaken National Park Management Board

Projects proposed by BNPMB respondents focused on objectives with "significant urgency". As one respondent noted, "These are the most important objectives for the island". The same respondent noted that these objectives would change, so it was necessary to address each objective as soon as possible. The five primary objectives focus mainly on coral condition. A distant interest is in grouper monitoring sites. In 2004, WWF initiated SPAGS (Spawning and Aggregation Sites), a monitoring program that involves identification of grouper spawning sites and monitoring the number of groupers at these sites every full moon. This program was currently underway and involved dive operator representatives and fishers. Because there was significant interest in this project from both primary stakeholder groups, the program was also of great interest to the Board. The five primary interests, identified by Board respondents included:

- To investigate coral condition in each zone.
- To evaluate the effectiveness of the zonation plan.
- To identify zones with the poorest coral reef condition.
- To identify the impact of garbage from Manado on the coral reefs.
- To identify changes in grouper monitoring sites.

A summary of the interests stated by Bunaken National Park Management Board stakeholders is provided in Table 7.5.

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Table 7.5. Results of the interpretation of project objectives and the translation of project objectives to habitat information available via the 2001 habitat map. Shaded columns represent elements translated by the researcher and NRM III personnel.

BNPMB	**Objective**	**Spatial Location and Extent** (Geomorph and Management Zones)	**Indicator(s)**	**Time Period of Interest**	**Habitat(s)**	**Spatial Scale**	**Temporal Scale**
1	To investigate coral condition in each zone.	Core zone, tourism zone, and general use zone.	Coral cover.		Coral (< 5m) Coral (5-15 m)		
2	To evaluate the effectiveness of the zonation plan.	Core zone.	Coral cover.		Coral (< 5m) Coral (5-15 m)	2001 and 2004	Yes
3	To identify zones with the poorest coral reef condition.	Tourism and general use zones.	Coral cover.		Coral (< 5m) Coral (5-15 m)		

4	To identify the impact of garbage from Manado on the coral reefs.	Tourism zone.	Coral cover. Presence of garbage.		Coral (< 5m) Coral (5-15 m)	2001 and 2004	Yes
5	To identify changes in grouper monitoring sites.	Grouper monitoring sites.	Increase or decrease in seascape relief.		Coral (5-15 m)	2001 and 2004	Yes

7.4.5 Scream and Natural Resources Management III

Objectives proposed by Scream and NRM III evolved from existing Scream and NRM III projects. For example, a Scream respondent noted that his organization was concerned about the recent increase in boat traffic around Bunaken Village. Several foreign fishing vessels had recently been seen anchored in the reef flat, and the physical impact on the reef was significant. In addition to foreign fishing vessels, regular boat traffic was increasing, and was 'likely' creating more scars on the reef crest.

> "We have seen a few boats from the Philippines anchor in the tidal flat. These boats are deep sea fishing boats. They are bigger than any of the boats on Bunaken Island. When they anchor in the tidal flat, they drag across the coral and the seagrass."

> "There are so many boats. We don't know why there are so many boats from the mainland. It's probably because there is a new dock now. The Seacology dock. That must bring in more boats. I have never seen so many boats before and I have lived on the island for many years."

Objectives proposed by NRM III respondents focused mainly on coral conditions, and on the condition of one site that recently had eco-reefs placed across the ocean floor. At Fukoi dive site, eco-reefs were clustered into groups of 30, creating an artificial reef to promote reef growth and to provide shelter for fish. The condition of the eco-reef was of great interest to NRM III respondents who believed that an artificial reef would have use in other areas if it was proven to be successful at Fukoi. The primary interests, identified by Scream and NRM III, are identified below.

- To identify the number of boat scars throughout the reef (Scream).
- To identify the impact of foreign fishing vessels on the reef (Scream).
- To compare coral condition at sites with high and low boat traffic (NRM III).
- To investigate the progress of existing eco-reefs (NRM III).
- To investigate the impact of sediment runoff on coral conditions (NRM III).
- To identify changes in coral conditions at the northwestern corner (NRM III).
- To compare the conditions of coral in front of Bunaken and Alung Banoa Villages (NRM III).

A summary of the interests stated by Scream and NRMII stakeholders is provided in Table 7.6.

Table 7.6. Results of the interpretation of project objectives and the translation of project objectives to habitat information available via the 2001 habitat map. Shaded columns represent elements translated by the researcher and NRM III personnel.

Group	**Objective**	**Spatial Location and Extent** (Geomorph and Management Zones)	**Indicator(s)**	**Time Period of Interest**	**Habitat(s)**	**Spatial Scale**	**Temporal Scale**
Scream *1*	To identify the number of boat scars throughout the reef.	Reef crest within the tourism and general use zones.	Number of boat scars.		Coral (< 5m)	Yes	
2	To identify the impact of foreign fishing vessels on the reef.	Reef flat and reef crest slope nearby Bunaken Village.	Number of boat scars. Decrease in seagrass spatial extent.		Seagrass Coral (< 5m)	Yes	
NRM III *1*	To compare coral condition at sites with high and low boat traffic.	Reef crest and slope nearby Bunaken Village and Pangalisang Beach.	Coral cover.		Coral (< 5m) Coral (5-15 m)	Yes	

2	To investigate the progress of existing eco-reefs.	Fukui dive site.	Presence of coral larvae.	2001 and 2004	Coral (< 5m) Coral (5-15 m)	Yes	Yes
3	To investigate the impact of sediment runoff on coral conditions.	Reef crest within the core zones.	Coral cover.		Coral (< 5m)	Yes	
4	To identify changes in coral conditions at the northwestern corner.	Reef crest and slope within the northwest corner.	Number of large boulders. Coral cover.	2001 and 2004	Coral (< 5m) Coral (5-15 m)	Yes	Yes
5	To compare the conditions of coral in front of Bunaken and Alung Banoa Villages.	Reef crest and slope in front of Bunaken and Alung Banoa Villages.	Coral cover.		Coral (< 5m) Coral (5-15 m)	Yes	

7.4.6 Universitas Sam Ratulangi

Objectives proposed by UNSRA respondents covered a range of topics. First, respondents were interested in identifying species at risk. According to one respondent, "It is crucial that we identify what species are at risk in the marine environment, and identify where they are located". A second respondent supported this statement, "We need to identify species at risk for our own knowledge and for the IUCN. We need to know if we can add species to the Red List". The IUCN Red List identifies threatened species that have been globally evaluated using the IUCN Red List Categories and Criteria. Other objectives include investigating the impacts of salinity and temperature on coral reefs, and nitrogen and phosphorous on seagrass. Similar to Scream and NRM III interests, UNSRAT interests evolved from current research projects. The five primary objectives include:

- To identify species at risk (IUCN categorization of species at threat of extinction).
- To investigate the impact of salinity and temperature on the coral reef.
- To investigate the impact of the Seacology dock on coral biodiversity.
- To investigate coral reef growth rates.
- To investigate the impact of nitrogen and phosphorous on seagrass.

A summary of the interests stated by Bunaken National Park Management Board stakeholders is provided in Table 7.7.

Table 7.7. Results of the interpretation of project objectives and the translation of project objectives to habitat information available via the 2001 habitat map. Shaded columns represent elements translated by the researcher and NRM III personnel.

UNSRAT	**Objective**	**Spatial Location and Extent** (Geomorph and Management Zones)	**Indicator(s)**	**Time Period of Interest**	**Habitat(s)**	**Spatial Scale**	**Temporal Scale**
1	To identify species at risk (C).	Reef flat, crest, and slope in all zones.	Unique hard or soft coral species.		Coral (< 5m) Coral (5-15 m)	Yes	
2	To investigate the impact of salinity and temperature changes on the reef (C).	Reef crest along the eastern side of the island.	Coral bleaching.		Coral (< 5m)	Yes	
3	To investigate the impact of the Seacology dock on coral biodiversity (C).	Reef flat and crest surrounding the Seacology dock.	Loss of hard coral cover.	2001 and 2004	Coral (< 5m)	Yes	2004 only
4	To investigate coral reef growth rates (C).	Core zones.	Increase or decrease in hard and soft coral species.	2001 and 2004	Coral (< 5m)	Yes	Yes

5	To investigate the impact of nitrogen and phosphorous on seagrass (F).	Reef flat in front of dive operations along the eastern side of the island.	Increase or decrease in seagrass spatial extent.	2001 and 2004	Seagrass	Yes	Yes

7.5 DEGREE OF ASSOCIATION

The degree of association was calculated for each objective, and the results are presented in Table 7.8. Results indicate that 66% of the objectives have 'strong' associations. This means that 66% of the indicators can be directly linked to a habitat (from the 2001 habitat map) at relevant spatial and temporal scales. In other words, 66% of the time, the 2001 remotely-sensed habitat map could address local coral reef management objectives identified by stakeholder respondents. However, one stakeholder group, Universitas Sam Ratulangi, had only one strong association between indicator and habitat, while the remaining indicator-habitat relationships were moderate to none. The 'feature(s) of interest', identified by respondents, can explain this: no feature(s) of interest were directly identifiable using the habitat data. Simply, the interests did not include coral, seagrass, sand, lagoon habitats. Although the results from this process do identify the relationship between indicator and habitat, they should be used with caution. Stakeholder interests change between years, and therefore, the strength of association may change. However, the overall strength of association does provide a good indication of how well, at a specific time, a remotely-sensed habitat map can address coral reef management objectives.

Table 7.8. Strength of association between indicators and habitats for each project objective by stakeholder group.

Objective	NSWA	BCCF	MofT	BNPMP	Scream	NRM III	UNSRAT
1	Strong	Strong	Strong	Strong	Strong	Strong	None
2	Strong	Strong	Strong	Strong	Strong	None	Weak
3	Strong	None	Moderate	Strong	N/A	Strong	Moderate
4	Strong	Strong	Moderate	Strong	N/A	Strong	Weak
5	Strong	Moderate	Weak	Weak	N/A	Strong	Strong

7.6 EVALUATION OF THE RESEARCH

In this chapter, a method for linking coral reef management projects, identified by stakeholders with remotely-sensed coral reef habitat data is proposed. The method requires knowledge of both the social and physical environments, and particularly the interests of the stakeholder groups and the 'feature(s) of interest' around which the interests are focused. Moreover, by the very nature of this research, stakeholder respondents were active participants in the decision-making process. Respondents identified local coral reef management projects, and then using their knowledge of the habitat map, identified which reef management projects might be addressed.

7.6.1 Strengths

- Identifying location (geomorphological and management zone) and indicator(s) was useful in clarifying the objective. This process was useful for avoiding inaccurate interpretations by the researcher and by research assistants, and for focusing the comments made by the stakeholder during the interview.
- Utilizing a team of experts (NRM III personnel) to assist with linking habitat(s) to indicator(s) provided the researcher with considerable insight to recent projects by stakeholder groups, the outcomes of these projects, and the general interests of respondents.
- Returning to respondents was useful for obtaining clarification and for establishing trust between the researcher and respondent. In many cases, respondents were more willing to provide information and to expand upon previous statements.

7.6.2 Weaknesses

- A large portion of this investigation involved the researcher's interpretation of the qualitative data. Therefore, it is likely that some information was not interpreted correctly. Possible causes of misinterpretation include cultural differences, language constraints, and lack of objectivity.
- Indicator-habitat linkage largely resulted from the researcher's and team members' knowledge of stakeholder interests and the biological environment, and ability to connect the two. Inaccurate linkages may have resulted.

- The degree of relatedness index is also highly dependent on the researcher's ability to correctly interpret and understand the indicator(s), as the stakeholder respondent identifies it. Within this process, there is potential for misinterpretation.

7.6.3 Conclusions and Future Research

The focus of this study has been to identify a process for linking coral reef management projects with habitats identified in the IKONOS habitat map. The next study will identify how the results of this study and the results of Chapter Six (map presentation) can be used to develop 'management maps' that address management objectives in a culturally appropriate format. This chapter concludes the third stage in the four-step strategy that seeks to guide the use of remotely-sensed information in coral reef management.

CHAPTER EIGHT:
INTEGRATING REMOTELY-SENSED HABITAT DATA AND CARTOGRAPHIC ELEMENTS

SUMMARY

This is the final stage in a strategy that guides the use of remotely-sensed information in coral reef management for Bunaken Island. In this chapter, a process that integrates management-specific remotely-sensed habitat data (Chapter Seven) and stakeholder-specific cartographic elements in a single map is produced. The resulting map is called a management map. This map provides an alternative to mainstream remotely-sensed habitat maps, differing in both content and appearance: the map addresses specific local coral reef management objectives in a form and language that is appropriate to the map reader. To address specific coral reef management objectives for each stakeholder group, objective from each group were linked to remotely-sensed habitats in Chapter Seven. To identify the appropriate form and language, stakeholder responses to 'map presentation' were collected in Chapter Six, and, organized into cartographic categories. Results from both of these efforts are integrated in a management map. For this research, one non-temporal and one temporal management map is created for each of the seven stakeholder groups. The non-temporal management maps illustrate habitat data taken from the 2004 remotely-sensed habitat map, while the temporal management maps illustrate habitat changes in coral and seagrass that were identified in the change detection analysis procedure in Chapter Five. Habitat change was calculated on a per-pixel basis using ENVI image processing software. Habitat data and cartographic elements are placed on a colour composite satellite image of Bunaken Island captured in 2004.

8.1 METHODS AND MATERIALS

The two data sets used in this research are (1) stakeholder responses to 'map presentation' (Chapter Six) and (2) management-specific remotely-sensed habitat data (Chapter Seven). In 2004, stakeholder responses to the 2001 remotely-sensed habitat map (Habitat types: coral (< 5 m deep), coral (5-15 m deep), seagrass, sand, silt, and lagoon) were collected using informal interviews and focus group techniques from May through June. Stakeholder groups included the North Sulawesi Watersports Association (NSWA), Bunaken Concerned Citizens Forum (BCCF), Ministry of Tourism (MofT), Bunaken National Park Management Board (BNPMB), Scream, Natural Resource Management III (NRM III), and Universitas Sam Ratulangi (UNSRAT). Questions asked of stakeholders included: What is your impression of the habitat map? Can you identify your village, nearby markets and docks? Do the colours clearly differentiate the habitat types? In addition to these questions, related questions were asked to clarify responses, to acquire more information, or to focus on a specific topic. Next, focus group discussions were conducted and held with NSWA, BCCF, BNPMB, BMPMB, and NRM III stakeholder groups. These discussions began with a brief presentation about the habitat map, map presentation, and map applicability. Participant comments and questions about map presentation were recorded. Responses from the informal interviews and focus group discussions were collated and then organized into tables that illustrate essential cartographic elements for each stakeholder group. An essential cartographic element is defined as a symbol or reference feature, or a map format that provides the reader with direction and understanding. Together the cartographic elements represent the specific language of cartography for a stakeholder group. Cartographic elements that are relevant to communicating non-temporal (Table 8.1) and temporal (Table 8.2) management-specific habitat data have been organized separately.

Table 8.1. Cartographic elements for non-temporal management-specific habitat data.

<table>
<tr><th></th><th>Description</th><th>NSWA</th><th>BCCF</th><th>M of T</th><th>BNPMB</th><th>Scream</th><th>NRM III</th><th>UNSRAT</th></tr>
<tr><td colspan="9">General Structure</td></tr>
<tr><td>Orientation</td><td>Alignment of map features.</td><td>North</td><td>North</td><td>North</td><td>North</td><td>North</td><td>North</td><td>North</td></tr>
<tr><td>Labels</td><td>North Arrow
Legend
Scale
Editor’s Notes
Title</td><td>Yes
Yes
Yes
Yes
Yes</td><td>Yes
Yes
Yes
Yes
Yes</td><td>Yes
Yes
Yes
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Yes</td><td>Yes
Yes
Yes
Yes
Yes</td></tr>
<tr><td>Language</td><td>Language used for title, legend, and editor’s notes.</td><td>English</td><td>Bahasa Indonesia and Bahasa Bunaken</td><td>Bahasa Indonesia and Bahasa Manado</td><td>Bahasa Indonesia and Bahasa Manado</td><td>Bahasa Indonesia and Bahasa Manado</td><td>English</td><td>English</td></tr>
<tr><td colspan="9">Reference Feature</td></tr>
<tr><td>General Features</td><td>Features, on the ground, that when included in the map provide, reference to position.</td><td colspan="7">Land
Docks
Markets
Churches
Villages
Mosques
Zonation Plan
Deep Water</td></tr>
<tr><td>Specific Features</td><td>Features, on the ground, that when included in the map, provide reference to position.</td><td>Dive Sites
Boat Channels</td><td>Dive Sites
Boat Channels</td><td></td><td></td><td></td><td>Dive Sites</td><td>Dive Sites</td></tr>
<tr><td>Base Layer</td><td>Background image on which habitat classification is placed.</td><td>Colour-composite</td><td>Colour-composite</td><td>Colour-composite</td><td>Colour-composite</td><td>Colour-composite</td><td>Colour-composite</td><td>Colour-composite</td></tr>
</table>

Habitat Type Identification								
General Habitat Type Identification	The manner in which habitat types are identified on the map.	Solid Colour	Solid Colour	Solid Colour	Solid Colour	Solid Colour	Solid Colour	Solid Colour
Differentiating Between Different Habitat Types	The manner in which different habitat types are differentiated.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.
Differentiating Between Similar Habitat Types	The manner in which similar habitat types are differentiated.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.
Map Extent								
Full or Partial Extent	Full extent represents the entire island. Partial extent represents a portion of the island that is of interest.	Partial	Partial	Full	Full	Full	Partial	Full

Table 8.2. Cartographic elements for temporal management-specific habitat data.

Item	Description	NSWA	BCCF	M of T	BNPMB	Scream	NRM III	UNSRAT
Cartographic Element								
Orientation	Alignment of map features.	North	North	North	North	N/A	North	North
Labels	North Arrow Legend Scale Editor's Notes Title	Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes	N/A	Yes Yes Yes Yes Yes	Yes Yes Yes Yes Yes
Language	Language used for title, legend, and editor's notes.	English	Bahasa Indonesia and Bahasa Bunaken	Bahasa Indonesia and Bahasa Manado	Bahasa Indonesia and Bahasa Manado	N/A	English	English
Reference Feature								
General Features	Features, on the ground, that when included in the map provide, reference to position.	Land Docks Markets Churches Villages Mosques Zonation Plan Deep Water						
Specific Features	Features, on the ground, that when included in the map, provide reference to position.	Dive Sites Boat Channels	Dive Sites Boat Channels	Dive Sites Boat Channels		N/A	Dive Sites	
Base Layer	Background image on which habitat classification is placed.	Colour-composite	Colour-composite	Colour-composite	Colour-composite	N/A	Colour-composite	Colour-composite

Habitat Illustration								
General Habitat Type Identification	The manner in which habitat types are identified on the map.	Solid Colour	Solid Colour	Solid Colour	Solid Colour	N/A	Solid Colour	Solid Colour
Differentiating Between Different Habitat Types	The manner in which different habitat types are differentiated.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.	N/A	Colours should reflect the natural colour of the habitat type.	Colours should reflect the natural colour of the habitat type.
Differentiating Between Similar Habitat Types	The manner in which similar habitat types are differentiated.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	N/A	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.	Colours should reflect the natural colour of the habitat type and be used in lighter (less) or darker (more) shades.
Habitat Change								
Illustration of Habitat Change	Increase Decrease No Change	Yes Yes Yes	Yes No No	Yes No No	Yes No No	N/A	Yes No No	Yes No No
Map Extent								
Full or Partial Extent	Full extent represents the entire island. Partial extent represents a portion of the island that is of interest.	Full	Full	Full	Full	N/A	Full	Full

Habitat data delineated within the IKONOS 2001 and 2004 satellite imagery and linked to coral reef management project objectives constitute the second data set. The process of linking habitat data with current coral reef management projects involved, first, deconstructing project objectives into indicator(s), spatial location and extent of indicator, and time period of interest, and, second, matching the delineated habitat data to each category. For example, NSWA stakeholders identified the following objective: to investigate the quality of dive sites. Quality is represented by the presence of living coral, while a dive site is represented by reef crest and slope areas visible during a dive. From the habitat map, the coral habitats (Coral (< 5 m deep) and Coral (5-15 m deep)) within the reef crest and reef slope areas, visible during a dive, are used to address the objective. When investigation of habitat change is part of the objective, the years for which change can be examined are identified. For each stakeholder group, up to five project objectives were identified. For each objective, indicator information was deconstructed and translated into habitat information. For this stage, these data have been pruned: two objectives have been identified for each stakeholder group, one non-temporal and one temporal. The first table (Table 8.3) details the non-temporal objectives by stakeholder group, while the second table (Table 8.4) details the temporal objectives by stakeholder group.

Table 8.3. Non-temporal project objectives, spatial location and extent, indicator(s), and habitat(s) categorized by stakeholder group.

Group	**Objective**	**Spatial Location and Extent** (Geomorphological and Management Zones)	**Indicator(s)**	**Habitat(s)**
NSWA	To investigate the quality of the dive sites.	Dive sites within tourism zones.	Coral cover	Coral (< 5m) Coral (5-15 m)
BCCF	To identify the seascape condition in which medicinal organisms can be found.	Tidal flat in all zones.	Increase or decrease in habitat connectivity	Coral (< 5m) Seagrass

M of T	To identify the overall condition of the coral reef environment.	Reef crest and reef slope in all zones.	Coral cover	Coral (< 5m) Coral (5-15 m)
BNPMB	To identify zones with the poorest coral reef condition.	Tourism zone and general use zone	Coral cover	Coral (< 5m) Coral (5-15 m)
Scream	To identify the number of boat scars throughout the reef.	Reef crest within the tourism and general use zones	Number of boat scars	Coral (< 5m)
NRM III	To compare coral condition at sites with high and low boat traffic.	Reef crest and reef slope nearby Bunaken Village and Pangalisang Beach.	Coral cover	Coral (< 5m) Coral (5-15 m)
UNSRAT	To identify the location of species at risk.	Reef flat, crest, and slope in all zones.	Coral cover	Coral (<5 m) Coral (5-15 m)

Table 8.4. Temporal project objectives, spatial location and extent, indicator(s), and habitat(s) categorized by stakeholder group.

Group	Objective	Spatial Location and Extent (Geomorphological and Management Zones)	Indicator(s)	Time Period of Interest	Habitat(s)	Spatial Scale	Temporal Scale
NSWA	To identify changes in dive site quality since inception of the zonation plan.	Dive sites within tourism zones.	Increase or decrease in coral cover and reef fish.	2001 and 2004	Coral (< 5m) Coral (5-15 m)	Yes	Yes
BCCF	To investigate changes in seagrass extent.	Seagrass within the reef flat.	Increase or decrease in seagrass spatial extent.	2001 and 2004	Seagrass	Yes	Yes

M of T	To assess the change in coral reef condition between years of high and low visitor numbers.	Reef crest and reef slope.	Coral cover.	2001, 2002, 2003, 2004	Coral (< 5m) Coral (5-15 m)	Yes	2001 and 2004 only
BNPMB	To identify changes in grouper monitoring sites.	Reef slope.	Increase or decrease in seascape relief.	2001 and 2004	Coral (5-15 m)	2001 and 2004	Yes
Scream	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NRM III	To investigate the progress of existing eco-reefs.	Fukui dive site.	Presence of coral larvae.	2001 and 2004	Coral (< 5m) Coral (5-15 m)	Yes	Yes
UNSRAT	To identify changes in seagrass coverage.	Reef flat	Seagrass	2001 and 2004	Seagrass	Yes	Yes

8.2 DATA PROCESSING

A step-by-step process (Figure 8.1) was used to construct two management maps for each stakeholder group. The first step involves selecting a project objective, and then selecting the associated habitat. Next, the habitat type is isolated. To isolate a habitat type, the display command is used in ENVI, and then the image is saved. The saved image is reopened in Adobe Illustrator and isolated by marking the surrounding area as transparent, and then saved. This saved image is called the 'habitat image'. Then the habitat image is overlaid on a colour-composite IKONOS 2004 satellite image of Bunaken Island. Image resolution, size, and position of the habitat image and colour-composite image are held constant to prevent image shifting during overlay. To isolate areas that have experienced a positive or negative change in habitat coverage, a change detection analysis was carried out between the 2001 and 2004 habitat images using ENVI. A positive change identifies pixels that were absent in 2001, but present in 2004, while a negative change identifies pixels that were present in 2001, but absent in 2004. For more details on the change detection analysis procedure see Chapter Five. When required to address a project objective that investigates changes in habitat coverage, one or both habitat change images (positive/negative) are opened in Adobe Illustrator and isolated by marking the surrounding area as transparent, and then saved. Then the habitat change image(s) is overlaid on a colour-composite IKONOS 2004 satellite image of Bunaken Island. Image resolution, size, and position of the habitat change image and colour-composite image are held constant to prevent image shifting during overlay.

The steps that follow involve isolating the area of interest, such as the dive sites, geomorphological and/or management zones, and then placing general and specific reference features and other cartographic elements on the map. The general and specific features include markets, churches, villages, mosques, dive sites, and boat channels. The geographic coordinates of these features were measured using a GPS during field surveys in 2001 and 2004 (Chapter Five) and these measurements are used to guide the features on the map.

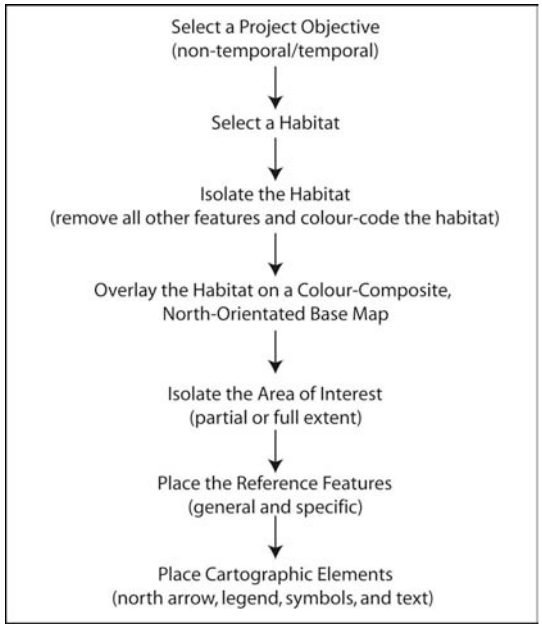

Figure 8.1. Summary of the step-by-step process used to construct a management map.

8.3 RESULTS

A management map (non-temporal and temporal) for each stakeholder group was produced. For each map, several changes were made to the illustrations that contrast with the cartographic elements requested by each stakeholder group. For example, markets, churches, and mosques were removed from all maps because these features are too small to discern. Also, all maps are illustrated in a full extent format. In a printed format, an appropriate map size was identified as 6' x 5', so that the map can be hung on a wall. To illustrate only a portion of the map specific details are required. However, these details area unavailable, and, as a result, a partial extent cannot be created. The colours of each habitat class were selected by the stakeholder groups. The colours of the zonation boundaries were not changed because the colours were selected by stakeholder groups during the zonation development process.

8.3.1 Non-Temporal Management Maps

8.3.1.1 North Sulawesi Watersports Association

The NSWA management map (Figure 8.2) addresses the following objective: to investigate the quality of the dive sites. NSWA stakeholders are particularly concerned about the condition of the coral reefs, and condition is believed to be influenced by divers. During an average dive, diver and the coral interaction is high with divers touching the reef, holding the reef, deliberately breaking living coral, standing, harassing megafauna, and disturbing sediment (DeVantier and Lyndon, 2004). Stakeholders are interested in comparing dive site quality and relating this information to the number of visitors at each dive site. This objective is addressed with a management map that details the condition of coral, expressed as living coral at different depths, within the spatial extent of each dive site. Shallow (<5 m) and deep (5-15 m) coral at dive sites were identified as most appropriate habitat types (Chapter Seven) and isolated, and then overlaid on a colour-composite IKONOS 2004 satellite image. The cartographic elements (general structure, reference features) were inserted into the map with relative ease. The cartographic elements included orienting the map northward, providing a north arrow, legend, mapmaker name and date, and appropriate title. English was used throughout the illustration. Illustration of habitats using 'colours that reflect the natural colour of the habitat type' was achieved by capturing colours of shallow and deep coral within an underwater photograph using the Adobe Illustrator CS colour capture function.

Figure 8.2. North Sulawesi Watersports Association Management Map (non-temporal).

8.3.1.2 Bunaken Concerned Citizens Forum

The BCCF management map (Figure 8.3) addresses the following objective: to identify the seascape condition in which medicinal organisms can be found. BCCF stakeholders have an interest in gathering small invertebrates from the tidal flat that include: *Andara sp., Mytilus sp., and Hippocampus sp*. These species are sold in the markets and used to treat ailments. The process of utilizing these species in daily foods and in local medicines is an important part of local tradition, and, in some cases, differentiates communities. This objective is addressed with a management map that details the condition of both coral and seagrass within the tidal flat zone that surrounds the island. Shallow (<5 m) coral and seagrass within the reef flat were identified as most appropriate habitat types (Chapter Seven) and isolated, and then overlaid on a colour-composite IKONOS 2004 satellite image. The cartographic elements (general structure and reference features) were inserted into the map with relative ease. The cartographic elements included orienting the map northward, providing a north arrow, legend, map-maker name and date, and appropriate title. Bahasa Indonesia was used throughout the illustration, and, wherever possible, Bahasa Bunaken was used. This means that terms most familiar to the BCCF stakeholder group were integrated when possible. These terms were identified during interviews and available from maps created by BCCF stakeholders. Similar to the NSWA map, most reference features were inserted into the map with relative ease, while markets, churches, and mosques were excluded. Habitat type colour was obtained using the process described above.

An important factor that was identified during interviews with members of BCCF was the associations placed on different colours. For example, one particular dive operation was particularly disliked by BCCF members and the dive operation chose to colour all of their boats orange. Consequently, any area marked in orange was associated with this dive operation. Therefore, the researcher noted that it was crucial not to illustrate different habitat types or changes in habitat types in this colour.

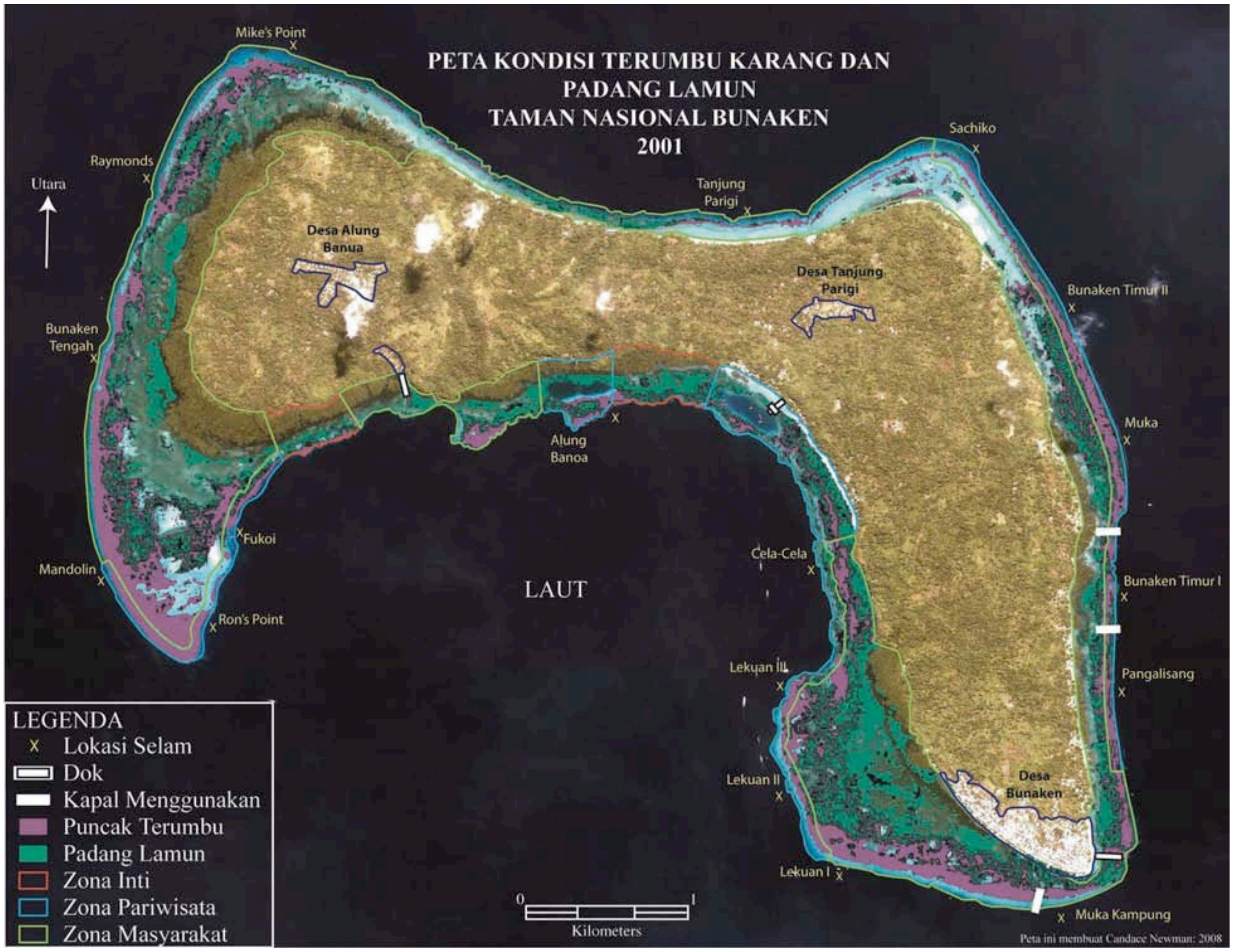

Figure 8.3. Bunaken Concerned Citizens Forum Management Map (non-temporal).

8.3.1.3 Ministry of Tourism

The Ministry of Tourism management map (Figure 8.4) addresses the following objective: to identify the overall condition of the coral reef environment. Members of the Ministry of Tourism expressed a great deal of interest in identifying the percentage of live coral throughout all geomorphological and management zones. Members wanted to use this information as a basis for upcoming advertisement campaigns, and to use any maps that clearly illustrate the high quality coral reef environment surrounding Bunaken Island. This objective is addressed with a management map that details the condition of coral, expressed as living coral at different depths, in all zones. Shallow (<5 m) and deep (5-15 m) coral within the reef crest and reef slope geomorphological zones and throughout all management zones were identified as most appropriate (Chapter Seven) and isolated, and overlaid on a colour-composite IKONOS 2004 satellite image.

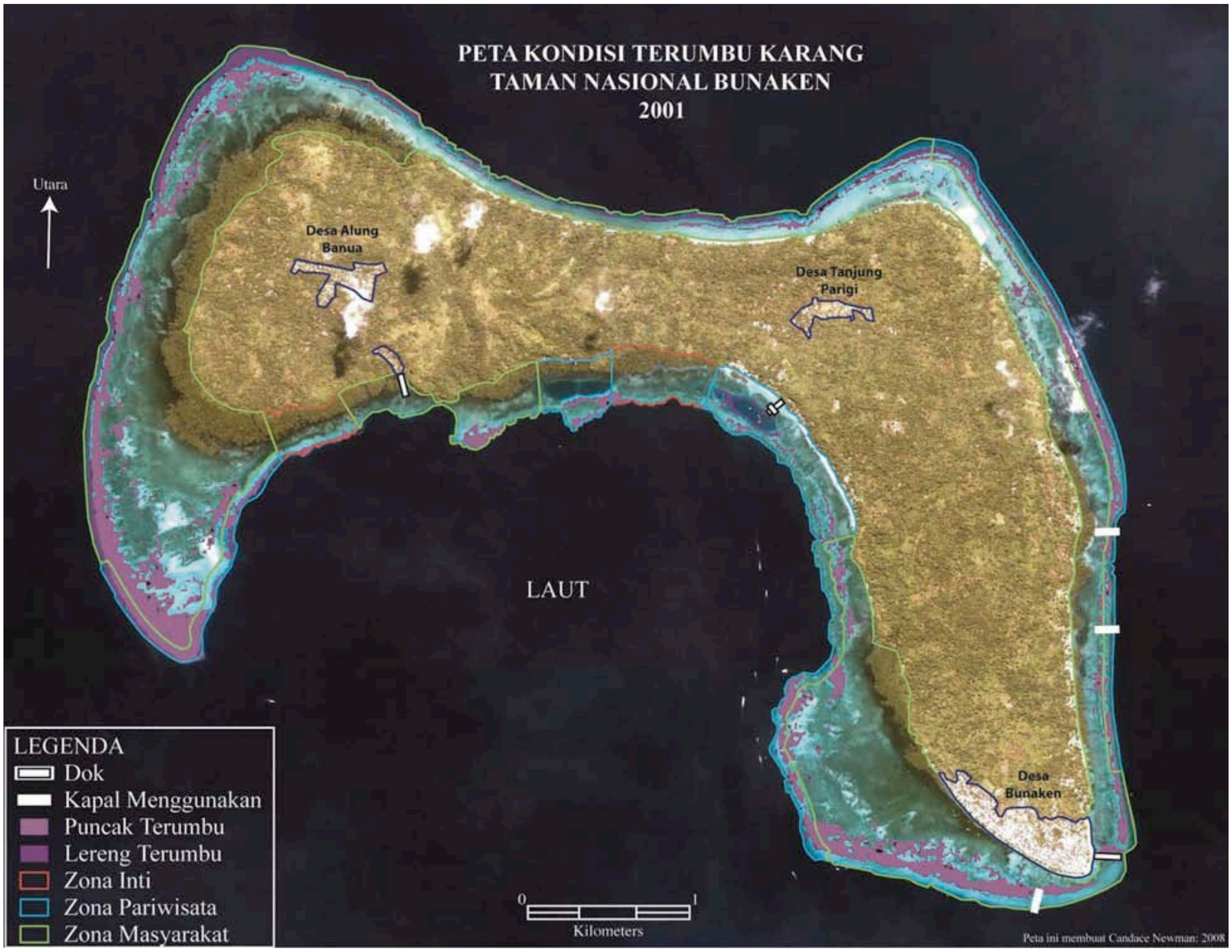

Figure 8.4. Ministry of Tourism Management Map (non-temporal).

8.3.1.4 Bunaken National Park Management Board

The BNPMB management map (Figure 8.5) addresses the following objective: to identify zones with the poorest reef condition. There was great concern for areas experiencing degradation, and discussions about the need to demarcate these areas as no-fishing or diving, recovery sites. Board members were concerned about how national and international attention had resulted in an increase in visitors to the island and, consequently, a greater impact on marine resources. This was exemplified in an increase in daily boating activity, diving activity, and tidal flat walks. This objective is addressed with a management map that details the condition of coral, expressed as living coral at different depths, within each geomorphological zone throughout he two management zones. Shallow (<5 m) and deep (5-15 m) coral throughout the reef flat, reef crest, and reef slope geomorphological zones and within the tourism and general use zones were identified as most appropriate habitat types (Chapter Seven) and isolated.

Figure 8.5. Bunaken National Park Management Board Management Map (non-temporal).

8.3.1.5 Scream

The Scream management map addresses the following objective: to identify the number of boat scars throughout the reef. Several boat trips to Bunaken Island by members of the local NGO, Scream, resulted in observations of 'scars' in standing coral structures from medium- and large-sized boats. Scream members were most interested in identifying locations with the highest number of boat scars and whether the locations could be connected to particular villages. This objective is addressed with a management map that details the condition of coral, expressed as living coral at different depths, within the reef crest within several management zones. Shallow

(<5 m) and deep (5-15 m) coral throughout the reef crest only and within the tourism and general use zones were identified as most appropriate habitat types (Chapter Seven).

Figure 8.6. Scream Management Map (non-temporal).

8.3.1.6 Natural Resources Management III

The NRM III management map addresses the following objective: to compare coral condition at sites with high and low boat traffic. Similar to the objective for Scream stakeholders, the NRM III objective focuses on coral condition, expressed as living coral, at sites with high and low boat traffic. Sites were identified by NRM III stakeholders. Drawing a connection between coral condition and boat traffic would permit stakeholders to propose alternative landing locations, which may reduce boat impacts on a single site. This objective is addressed with a management map that details the condition of coral, expressed as living coral at different depths, within preselected sites around the island. Shallow (<5 m) and deep (5-15 m) coral throughout the reef crest and reef slope geomorphological zones in front of Bunaken Village and Pangalisang Beach were identified as most appropriate habitat types (Chapter Seven).

Figure 8.7. Natural Resource Management III Management Map (non-temporal).

8.3.1.7 Universitas Sam Ratulangi

The UNSRAT management map addresses the following objective: to identify the location of species at risk. UNSRAT stakeholders identified several species at risk within the shallow waters surrounding Bunaken Island. During discussions, the health of most species was connected to the condition of the coral reef environment. Therefore, evaluation of coral condition was deemed an appropriate indirect measure of species at risk condition. This objective is addressed with a management map that details the condition of coral, expressed as living coral at different depths, within all geomorphological and management zones. Shallow (<5 m) and deep (5-15 m) coral throughout all zones were identified as most appropriate habitat types (Chapter Seven).

Figure 8.8. Universitas Sam Ratulangi Management Map (non-temporal).

8.3.2 Temporal Management Maps

8.3.2.1 North Sulawesi Watersports Association

The NSWA temporal management map (Figure 8.9) addresses the following objective: to identify changes in dive site quality since inception of the zonation plan. NSWA stakeholders, as well as many other stakeholder groups, were interested in knowing how the zonation plan had improved the condition of the coral reef environment. NSWA stakeholders were most interested in whether the quality of a dive site, defined as living coral cover, had increased since 2001. Habitats used to address this objective included shallow (<5 m) and deep (5-15 m) coral at each dive site from the 2001 and 2004 habitat maps. A comparison of coral cover, for each dive site, between 2001 and 2004 produced an increase, decrease, and no-change result. These changes are identified using colours that were identified by stakeholders during interviews and include:

increase (green), decrease (red), and no change (yellow). In total, eight dive sites experienced an increase in coral cover, six dives sites experienced a decrease in coral cover, and two sites experienced no-change. No change is defined as a change of less than 5% in coral cover. Although the amount of change in coral cover was not illustrated within the image, the amount was calculated and is listed in Table 8.5. Cartographic elements, except for markets, churches, and mosques, were inserted with relative ease, and English was used as the primary language of communication.

Figure 8.9. North Sulawesi Watersports Association (temporal) Management Map.

Table 8.5. Absolute change in coral cover at dive sites.

Dive Site	Amount of Change Between 2001 and 2004
Fukoi	+11%
Ron's Point	+9%
Mandolin	+9%
Bunaken Tengah	3%
Raymonds	-8%
Mike's Point	-7%
Tanjung Parigi	-
Sachiko	4%
Bunaken Timur II	+11%
Muka	+10%
Bunaken Timur II	+9%
Pangalisang	+8%
Muka Kampung	-12%
Lekuan I	+7%
Lekuan II	+8%
Lekua III	-6%
Cela-Cela	-7%
Alung Banua	-9%

8.3.2.2 Bunaken Concerned Citizens Forum

The BCCF temporal management map (Figure 8.10) addresses the following objective: to investigate changes in seagrass extent. The extent of seagrass was believed to be highly correlated to the number of reef fish surrounding the island, and more fish was related to a greater resource from which profits could be made. Seagrass habitat, within the reef flat, identified in the 2001 and 2004 habitat maps was used to address this objective. Because stakeholders were most interested in areas that experienced an increase in seagrass, only areas that met this criterion were illustrated. The result was numerous individual or few clustered pixels scattered throughout the reef flat. On the map, these pixels are difficult to discern. BCCF stakeholders did not request for the amount of seagrass cover change to be illustrated on the map; however, seagrass cover change was calculated between the 2001 and 2004, and the result is an overall increase of 3%.

Figure 8.10. Bunaken Concerned Citizens Forum (temporal) Management Map.

8.3.2.3 Ministry of Tourism

The MofT temporal management map (Figure 8.11) addresses the following objective: to assess the change in coral reef condition between years of high and low visitor numbers. Coral condition is defined as living coral. MofT stakeholders discussed the threshold of the coral reef environment to sustain high visitor numbers. Habitat data used to address this objective included shallow (<5 m) and deep (5-15 m) coral, within the reef crest and reef slope, which were compared between 2001 and 2004. In 2001, there were 2,500 visitors to Bunaken Island, while in 2004 there were 4,600 visitors. A comparison of coral cover, between 2001 and 2004 produced an increase, decrease, or no-change result. A 5% threshold was used to differentiate between change and no-change areas. Because stakeholders were most interested in areas that experienced an increase in shallow or deep coral, only areas that met this criterion were illustrated. This resulted in numerous individual pixels and clustered pixels at various locations throughout the reef flat. On the map, the clustered pixels can be discerned. Coral cover change, between the 2001 and 2004, is an increase of 2% of shallow coral (< 5m) and an increase of 0.8% in deep coral (5-15 m).

Figure 8.11. Ministry of Tourism (temporal) Management Map.

8.3.2.4 Bunaken National Park Management Board

The BNPMB temporal management map (Figure 8.12) addresses the following objective: to identify changes in grouper-monitoring sites. Grouper monitoring sites were identified by stakeholders, and if monitoring results suggested degradation in the site, several Board members suggested implementing a regulation of no fishing and diving. Habitat data used to address this objective included deep (5-15 m) coral, within the reef slope, which were compared between 2001 and 2004. Although the locations of monitoring sites is known, BNPMB stakeholders were interested in identifying locations that experienced an increase in deep coral cover since 2001. These sites could be identified as potential future monitoring locations. A comparison of coral cover, between 2001 and 2004, produced an increase, decrease, or no-change result. A 5% threshold was used to differentiate between change and no-change areas. Because stakeholders were most interested in areas that experienced an increase in deep coral, only areas that met this criterion were illustrated.

Figure 8.12. Bunaken National Park Management Board (temporal) Management Map.

8.3.2.5 Natural Resources Management III

The NRM III temporal management map (Figure 8.13) addresses the following objective: to investigate the progress of existing eco-reefs. Habitat data used to address this objective included shallow (< 5m) and deep (5-15 m) coral, at Fukoi dive site, which were compared between 2001 and 2004. On 20 July 2004, dive guides and guests from thirteen dive operators from the North

Sulawesi Watersports Association (NSWA) joined the village of Alung Banua on Bunaken Island to install 300 ecoreef modules on a section of reef that had previously been degraded into a rubble field. Located beside Fukui dive site in Bunaken National Park, this rehabilitation marked the second such installation in the Park. The installation of the ceramic snowflake-shaped modules provided an increase in the three dimensional structure of the degraded rubble fields. Divers returned the following day to complete an initial round of coral transplantation, which involved wedging hundreds of live coral fragments (harvested from large healthy coral colonies from adjacent reefs) into the ceramic modules. This transplantation effort was initiated to promote rapid coral recovery in the previously flattened rubble field. According to some studies, these fragments will biologically cement themselves to the modules and resume growth. Combined with natural recruitment of juvenile corals to the structures, the area can be expected to host a thriving coral reef within 3-5 years if well managed. Because the eco-reefs were installed prior to image capture, the investigation of coral cover change around Fukui dive site reveals changes in coral cover, and not ecoreef condition. A comparison of coral cover between 2001 and 2004 indicated an increase, decrease, or no-change result. A 5% threshold was used to differentiate between change and no-change areas. Because stakeholders were most interested in areas that experienced an increase in shallow and deep coral, only areas that met this criterion were illustrated.

Figure 8.13. Natural Resource Management III (temporal) Management Map.

8.3.2.6 Universitas Sam Ratulangi

The UNSRAT temporal management map (Figure 8.14) addresses the following objective: to identify changes in seagrass coverage. Seagrass habitat, within the reef flat, identified in the 2001 and 2004 habitat maps was used to address this objective. Because stakeholders were most interested in areas that experienced an increase in seagrass, only areas that met this criterion were illustrated.

Figure 8.14. Universitas Sam Ratulangi (temporal) Management Map.

8.4 EVALUATION OF THE RESEARCH

In this section, the steps of the stage area assessed and how this research contributes to the last stage in the strategy are described.

8.4.1 Strengths

- Stakeholder groups define the language of communication as well as the form and style in which habitat information should be communicated.
- The cartographic element tables provided the researcher with a clear and systematic outline of each element and how it should be displayed, and also helped to reveal the differences and similarities between the languages of communication.

- Associations between stakeholder and management objective are made using language defined by each stakeholder group, and, as a result, are recognized and understood.

8.4.2 Weaknesses

- Complete details about partial extent illustration were not investigated and, therefore, could not be addressed.
- Several Bahasa Indonesia terms used in the illustrations are specific to the stakeholders interviewed. It is possible that other terms would have been collected and, subsequently, used if different stakeholders were interviewed or were part of the focus groups discussions.
- File size became a problem when developing the images. Because a single image is a composition of multiple layers that have text, symbols, and images, file size became so large that all image files had to be reduced. Without reducing the file size, programs crashed regularly or simply would not open. However, in doing this, in making the file smaller and therefore more transportable and usable, resolution is compromised. Therefore, this may pose a considerable challenge in the future if these images are printed in a large format (poster- or wall-size).

8.4.3 Conclusions and Future Research

In this chapter, a process that integrates management-specific remotely-sensed habitat data (Chapter Seven) and stakeholder-specific cartographic elements to produce management maps (non-temporal and temporal) is demonstrated. The data used in this research are dependent on the level of accuracy of data that were collected, processed, and interpreted in previous chapters. The management maps presented here communicate management-specific information in a language that is recognized and understood by the reader. The process identifies one technique for identifying the language of communication and translating this language on to a map. With an understanding of the social environment, this process has the potential to become a rapid method for producing maps that contain relevant information for coral reef managers.

CHAPTER NINE:
EVALUATING THE HABITAT AND MANAGEMENT MAPS

In this chapter, whether the strategy and the resulting management maps are an improvement over traditional remotely-sensed habitat maps as input to coral reef management projects is evaluated. The evaluation involves exploring initial stakeholder responses to the traditional habitat maps, examining how the maps subsequently changed in both content and appearance, and then exploring stakeholder responses to the management maps. A framework was designed to permit comparisons between the habitat and management maps across a range of indicators that emerged through interviews. Indicators determined as appropriate for identifying improvement include (1) statements of usefulness for management projects, (2) discussions about management, (3) development of specific management ideas, (4) influence on management decisions, and (5) direct application to management projects. In the following sections, whether an increase or decrease in improvement occurred for each indicator, and for each stakeholder group, is described and the results are then summarized.

9.1 RESPONSES TO THE REMOTELY-SENSED HABITAT MAP

During informal interviews, respondents from each stakeholder group made numerous comments about map content, presentation, and applicability to current and future coral reef management projects.

> "We know where the resources are. I collect resources daily. I know where I can find the fish and where the fish will be healthy. I don't need a map to show me that. Wait, your map doesn't show me that!" BCCF Respondent.

> "Although your map shows us where we can find some of the main resources, it doesn't tell us which species are in the coral class. We need to know the species that are in each class. Species information is critical to developing monitoring and protection programs, and to capture international attention and funding." UNSRAT Respondent.

"The map does not show the zones! I cannot read this map clearly because the zones are not here. You will see that most of the maps we use show the zones." BNPMB Respondent.

"We can use this map to identify how many mangroves have been cut down. Mangroves are protected on Bunaken Island. No one should be building anymore. Some people still build and they are not allowed. We can learn about the mangroves." Ministry of Tourism Respondent.

"How can I use the map if I can't see where I live? This map does not show some important places. You need to show the docks, the villages, and the boats. We need to see where we live. We need a map that looks real." BCCF Respondent.

These statements highlight some shortcomings of the traditional habitat map. First, the map does not necessarily identify habitats of interest to respondents. According to numerous statements, identified above, and observations by the researcher, the habitat types of interest are not illustrated within the map. Second, the habitat map does not provide appropriate orientation features, and therefore, respondents are challenged to recognize and understand the mapped information. However, the habitat map does enable monitoring of easily mappable resources such as mangrove, as noted by the respondent from the Ministry of Tourism. This observation was made on repeated occasions with different respondents.

A noteworthy observation repeatedly made throughout this research was the habitat map contained numerous habitat types that were irrelevant to stakeholders' interests. The comments were not stated directly nor did they target specific unwanted habitats. Rather, the comments were made by referring to the inability of the map, as a whole, to address their coral reef management concerns. Comments included, "… we know where the resources are located", or "… the map doesn't show me anything I don't already know." Shortly following these comments, in some cases, the respondent dismissed even any potential applications of the map to coral reef management, while in a few specific examples it became evident that the legitimacy and value of the map was diminished by the inclusion of the irrelevant habitats. Although the researcher experienced only a few of these situations, they highlight an important issue: habitat maps, if developed inappropriately, may discourage stakeholder involvement in projects intended to address coral reef management concerns. However, it is important to note that the researcher encountered minimal discouragement from stakeholders actively involved in the research.

9.2 CHANGES FROM HABITAT TO MANAGEMENT MAPS

Implementation of this research resulted in considerable changes to the habitat map in both content and appearance. The most significant changes included illustrating only habitats of interest, as well as cartographic elements identified as important to the given stakeholder. These changes are in themselves technically simple, but they signify a more profound change – the map content is now defined by the needs of the user, rather than by the capability of the technology with which it was produced. The habitat map is transformed from an expert-oriented map to a community-oriented map, and is now more appealing to potential users of the information it contains.

9.3 RESPONSES TO THE MANAGEMENT MAP

In general, responses to the management maps were numerous, and mainly positive. Observations made to the researcher include discussions about the management maps and management decisions being made on the basis of the maps. Many of these comments are provided below.

> "I think the management map is good because it tells me what I want to know. I wanted to know about where there is a lot of seagrass when you first came to speak with me. Now, I can see the seagrass clearly in the map." BCCF Respondent.

> "It's important that we know which dive sites have a lot of healthy coral. It's important for us to know this information each year. If we know which dive sites do not have healthy coral than we can make changes to our operation and suggest to our friends that they do the same!" NSWA Respondent.

"Generally, the management map is useful. It tells me where the coral is located. However, I'm still unhappy with the detail. I really need to know where specific coral species are located. The map doesn't show me this information, but I can use it to focus my research investigations." UNSRAT Respondent.

"The management map is excellent! We are very happy. We think we can use this map in our brochures, but it needs to be brighter, we need more colour! Can you do this?" Ministry of Tourism Respondent.

"Yes, we are very happy with the map. It would also be useful if we could import the map into ArcGIS. We are currently evaluating the effectiveness of the zonation plan and it would be nice if we could include some of the information on the map." NRM III Respondent.

"I really like how the management map is produced in Bahasa Indonesia. This is very unlike many mapping projects that have mapped Bunaken Island. It is very important that the people who are going to use the map can read it." Scream Respondent.

"Generally, many of our Board members do not speak during meetings. This began a long time ago. It is only the strong ones who speak; others are not brave enough to speak out. The map gave the weaker people an opportunity to speak." BNPMB Respondent.

"We think this map is very valuable. We want to share the information with our friends and discuss whether we should continue to fish in the reef flat around the villages. It appears that these areas are suffering from all of the boat traffic. I know the boats destroy the seagrass. Each day I can see the cuts in the seagrass. This is because the propellers are too close to the bottom." BCCF Respondent.

"I really like how we can see changes in the amount of coral at each dive site. This information really helps me. Can you create a large poster of the management map? I would like to post the image on the wall for our visitors to see." NSWA Respondent.

These statements bring attention to several issues concerning the management map. First, the management map is recognized as valuable because it identifies habitats of interest to a given stakeholder. Second, the map initiates discussions about a coral reef management project as well as possible solutions. Third, the map communicates the information quickly through the use of relevant features and the use of the local language. Fourth, the map is understood and can be explained by stakeholders to other stakeholders. Fifth, when the map does not directly address a coral reef management project, as was commented on by an UNSRAT respondent, it still provided information relevant to the project, which could be used in the respondent's own research.

9.4 A COMPARISON BETWEEN THE HABITAT AND MANAGEMENT MAPS

The framework presented below (Table 9.1) was designed to permit comparisons between the habitat and management maps across a range of indicators. In the remainder of this chapter, we illustrate the changes between the two maps, and through the use of the framework conclude that the management map is a considerable improvement over traditional remotely-sensed habitat maps, as input to coral reef management projects. Table 9.2 illustrates whether an improvement occurred in each indicator for each stakeholder group.

Indicator	**Stakeholder Group**	
	Habitat Map	**Management Map**
Statements of usefulness for management projects		
Discussions about management		
Development of specific management ideas		
Influence on management decisions		
Direct application to management projects		

Table 9.1. Framework for structuring an evaluation of the habitat and management maps.

9.4.1 Statements of Usefulness for Management Projects

During the final research period, there were two prominent examples where information from the management maps was used successfully to communicate with members of a stakeholder group and to influence decisions.

The first situation involved the BCCF stakeholders. Members of BCCF met on the island of Manado Tua in September 2004. Members from each of the five islands within Bunaken National Park attended, as well as several members from the two mainland portions of the Park. Discussions focused on three main topics that included fishing regulations, zonation violations, and grouper spawning-site monitoring plans. Extra time at the end of the meeting was reserved for discussion of the management maps; however, in the middle of discussions about zonation violations, members asked that the management map be displayed so the zone, which was being discussed, could be identified. Following display of the map, the researcher was asked to describe the content of the map. It was immediately evident that BCCF members could understand and orient themselves to the map.

Discussions turned quickly to the information on the management map. BCCF members noted the spatial location and extent of seagrass and general impressions were that seagrass exists in high concentrations around Bunaken Island, except for areas nearby docks and villages. When members then viewed the change in seagrass extent, the general impression was one of concern. The majority was concerned that the concentration of seagrass had increased minimally since the inception of the zonation plan. Immediately, discussions began about why this was the case, and then followed with how fishing pressure might be a cause. Several seagrass management decisions were made. The one that received the greatest amount of support was that reef fishers would redirect their fishing efforts to the reef crest, thereby avoiding the reef flat and permitting smaller fish the opportunity to grow and reproduce.

The second situation involved the NSWA stakeholder group. Following development of a management map that identifies changes in live coral cover at each dive site, the researcher presented the management map to NSWA members. The members immediately identified the location of dive sites and zonation boundaries. Several members were confused by the placement of the dive sites, so the researcher explained the strategy that was used to identify each site and the extent of each site. Next, with minimal explanation, the members identified dive sites that had high coral cover, and noted that these sites would be visited on their next dive. One member noted that the 'percentage of change' at each site would be most useful for comparisons. The member also noted that such values should be placed on the map, and given to all dive operators who are members of the NSWA.

In comparison, statements about the usefulness of the habitat map were predominantly negative and underlined the deficiencies of this map, as reviewed above. The one exception was the statement by the MofT respondent, who saw the potential for using habitat maps to monitor the cutting of mangroves.

9.4.2 Discussions About Management

Management maps created for BNPMB stakeholders were used during a BNPMB meeting to influence participating government officials. When the management map was presented to government officials, they were initially uninterested, stating that they had seen many maps of Bunaken Island and "… are very familiar with the marine resources." However, several BCCF and BNPMB representatives insisted that the management map be discussed. The map focused discussions on the coral condition in each zone, and the need to identify management zones with deteriorating reef conditions.

Shortly after the map was passed around the table, government officials made several comments about the presentation of the map, including "Which [management] zones are actually worse off than others?" , "I cannot determine which [management] zones are poorer [unhealthy coral] than others?" The comments suggested that the presentation of the habitat data was unclear and/or insufficient for government officials, who are recognized members of the BNPMB. The comments also suggested that data, beyond the illustration of habitats, were necessary to communicate the relevant information. Moreover, these data would best be presented in the form of percentages, such as the percentage change of live coral cover.

Although government officials did not fully understand the management map, they did continue discussions about the coral condition in each zone, and the need to identify management zones with deteriorating reef conditions. One BCCF member noted, "The government officials are paying more attention to the important issues." The comment, in this context, suggested that because the management map had involved input from Board members, the map itself held a greater value to the government officials: the management map provided Board members with an effective medium for communication that had previously been unavailable. In addition, the map brought increased legitimacy to the coral reef management concerns of Board members, thereby allowing them to have greater influence in their social environment.

The habitat map also once became the focus of a discussion about management, during a conversation with Two-Fish Divers. The dive operator was interested in creating a new channel for boating across the reef crest, and wanted to create the channel where two habitat types, seagrass and coral, met. The habitat map clearly showed the location of these habitats, and could have been used for this purpose if the plan had been carried to completion.

9.4.3 Development of Specific Management Ideas

A number of different management ideas emerged during management map discussions between stakeholders. These ideas include:

- Changes in fishing locations (BCCF Respondent)
- Changes in dive site selection (NSWA Respondent)
- Redirection of research on coral health (UNSRAT Respondent)
- Reproduction of management maps and distribution to community (NSWA Respondent)
- Printing of management maps on posters (NSWA Respondent)
- Efforts to reduce boat traffic
- Creation of a 'coral health' monitoring team
- Presentation of maps at community meetings
- Discussions of maps at national events
- Use of maps in tourism brochures
- Use of maps in newspapers and television

- Communication of coral health to visitors

During discussions involving the habitat map, different management ideas also emerged. These ideas include:

- Establishment of fish monitoring sites (BCCF Respondent)
- Evaluation of coral health in each management zone (MofT Respondent)
- Identification of 'coral hot spots', areas at risk of deterioration (UNSRAT Respondent)
- Comparison of coral health between years (NRM III Respondent)
- Development of a coral reef recovery strategy (BNPMB Respondent)
- Investigation of coral geological history (NRM III Respondent)
- Identification of anthropogenic impacts on shoreline coral (NSWA Respondent)

9.4.4 Influence on Management Decisions

All stakeholder groups were presented with management maps, and the general responses were positive. In addition, responses indicated recognition and understanding of the habitat data. These responses suggested that stakeholders understood the intended information.

What was of primary interest was whether the management maps were assisting stakeholders in making informed coral reef management decisions. Although it was not possible to conduct a full evaluation of management map use, stakeholders did provide the researcher with examples of how the 'new information' was being applied. One NRM III member noted, "Our management map identifies trouble with the coral reefs around Bunaken Island. We already knew this, but it is nice to have a map to show stakeholders who are skeptical." Pointing to the map, one BCCF member noted, "The management map is showing us where we are loosing seagrass, so I want to tell my friends [fishers] to avoid these areas." One NSWA member noted, "We need to discuss what this map is showing us with other NSWA friends. There are some dive sites that need time to recover, and we should make an active effort to avoid these sites." When these comments are compared with the comments regarding the original habitat map, it is evident that the content of the management map addresses, more directly, the interests of the stakeholders, and communicates this information in a culturally recognizable form. These comments suggest that stakeholders recognize the habitat information as relevant.

9.4.5 Direct Application to Management Projects

At the outset, the researcher speculated that a management map for a given stakeholder group would be used at some point for a management project. Nearing the end of the last field expedition, a temporal NSWA management map was used during an NSWA meeting. The meeting was called by several members who were concerned about the amount of coral breakage occurring at dive sites. According to these members, coral breakage was happening during every dive, primarily by tourists who were interested in capturing photographs of microorganisms such as seahorses and shrimp, and there was considerable interest in identifying and implementing a solution. During the meeting, the NSWA respondent who had been involved in developing a management map spoke up and brought attention to the temporal map identifying changes in live coral cover between 2001 and 2004. The respondent communicated the information he had learned from the map; some dive sites were experiencing a decrease in live coral cover while other dive sites were experiencing an increase. Discussions then began about whether coral breakage by tourists could be linked to dive sites experiencing a loss in coral. A decision about whether this was true could not be made; however, a decision about how to address the loss in coral was made. NSWA members agreed that they would more closely monitor dives sites that had experienced a loss, and this would be done by redirecting diving students, who were working towards a Dive Master Certification, to these dive sites and having them map the spatial location and extent of living coral. Inherent in the Dive Master Certification course is an underwater mapping component, so NSWA members decided to focus the mapping exercise on dive sites with low coral cover. Members believed that this approach would help them to identify how quickly changes in live coral cover were happening and whether additional responses were required. In comparison, the habitat map found no direct application in management projects. This prompted the researcher to explore techniques that could be used to determine the extent to which the management maps were used for direct application. One technique involves identifying the extent to which the maps are used in discussions at stakeholder meetings. A second technique involves charting the information that is derived from a management map through planning and implementation stages of management projects.

	BCCF		NSWA		MofT		BNPMB		Scream		NRM III		UNSRAT	
	HM	**MM**	**HM**	**MM**	**HM**	**MM**	**HM**	**MM**	**HM**	**MM**	**HM**	**MM**	**HM**	**MM**
Statements of usefulness for management projects	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓
Discussions about management	✓	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓	✗	✓
Development of specific management ideas	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✓	✓
Influence on management decisions	✗	✓	✗	✓	✗	✓	✗	✓	✗	✗	✗	✓	✗	✓
Direct application to management projects	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

Table 9.2. A summary of the improvements made for each indicator by stakeholder group. HM = Habitat Map; MM=Management Map. Check marks indicate that improvements were made while an 'x' indicates that no improvements were made.

9.5 CONCLUSION

The results presented here demonstrate that the management maps are an improvement over traditional remotely-sensed habitat maps as input to coral reef management projects. The framework presents a clear and logical structure that allowed the research to categorize the field data and enabled evaluation. The framework also helped to reveal the indicators that were instrumental for determining whether habitat data addressed coral reef management projects. One drawback lies in the indicators themselves, as the researcher's interpretation of the qualitative data might not have been correct when forming the indicators. Possible causes of error include cultural differences and language constraints. To address this constrain in future projects, researchers should involve local community members more directly in the interpretation of the data.

CHAPTER TEN:
SUMMARY

Mapping coral reef environments using satellite imagery has long been a response to the coral reef crisis. The non-invasive, rapid, and synoptic characteristics of satellite imagery make the technique appealing and desirable to both scientists and managers. Whether a remotely-sensed coral reef habitat map contains the relevant content in an appropriate language and form, however, is uncertain. This was the focus of this research.

In response to this uncertainty, the researcher developed a strategy that transforms traditional habitat maps, developed using remote sensing technologies, to management maps, maps that delineate habitats that are relevant to coral reef managers in a manner in which the information can be read and interpreted. The strategy includes four stages, three of which involve seeking and incorporating stakeholder feedback. The strategy is founded in the idea that stakeholders themselves would be participants in developing a management map, which would contain habitat data that address current coral reef management objectives and would communicate the habitat information in a language commonly recognized and understood by the stakeholder group. The stakeholders would be informed of the limitations of the habitat data and would not be coerced into accepting habitat data that did not address their management objectives. This would provide the researcher with insight into the relevance of the habitat data, and provide the stakeholders with knowledge and awareness of the applicability of remotely-sensed data to coral reef management projects. To this end, the strategy utilizes both quantitative and qualitative data collection and analysis techniques, and integrates these data sets. The methods used in this dissertation are new, innovative, and represent a significant contribution to the application of habitat maps, developed using remote sensing techniques, to coral reef management in developing countries.

10.1 THE STRATEGY

The strategy was developed to address the research question. It assumes the perspective of a coral reef remote-sensing scientist and suggests that the scientist will actively engage in qualitative research to uncover stakeholders' responses to a traditional remotely-sensed habitat map that delineates the coral reef habitats surrounding Bunaken Island.

The strategy involves four stages, each with a specific objective: develop a remotely-sensed coral reef habitat map, identify stakeholder receptivity to the habitat map, link stakeholder interests with habitat data, and illustrate the linked information. Using observations from the physical and social environments and comments and suggestions from stakeholders both within the study area and from faculty members at the University of Waterloo, a variety of methods were developed and employed in each stage. The strategy requires that each objective be achieved in a sequential order, so that the results from one stage can be used as input to the following stage. The first stage of the strategy is introduced in Chapter Five, and in Chapters Six to Eight each subsequent stage is addressed. These stages are briefly summarized below.

10.1.1 Stage One: Development of a Remotely-Sensed Coral Reef Habitat Map

In the first stage, image and field data were collected for Bunaken Island to develop a remotely-sensed coral reef habitat map. The methods to generate the habitat map are commonly used in remote sensing-based coral reef studies. The habitat map identified six different habitat categories, including coral (< 5 m deep), coral (5-15 m deep), seagrass, sand, silt, and lagoon, with an overall mapping accuracy of > 80%. This process was repeated again in stage two, thereby creating two habitat maps (2001 and 2004) for this researchfor the 2004 IKONOS satellite image data.

10.1.2 Stage Two: Stakeholder Receptivity to the Habitat Map

The methods described in stage two involved investigating stakeholder receptivity to the 2001 habitat map developed in stage one. The techniques were grounded in the broad field of qualitative research and were designed to lead the researcher to an understanding of stakeholder perception of map content, map presentation, and map applicability. Qualitative gathering tools included informal interviews, focus group discussions, and participant observations. Informal interviews involved the use of an informal questionnaire that contained open-ended questions to obtain the undirected opinions of respondents. Each technique utilized the habitat map as the focus of discussion. To the best of the researcher's knowledge, stage twoStage Two is the first study of its kind that actively investigates stakeholder receptivity to a remotely-sensed coral reef habitat map.

10.1.3 Stage Three: Linking Coral Reef Management Projects with Remotely-Sensed Habitat Data

The methods in stage threeStage Three provide an objective and systematic approach for deconstructing stakeholder feedback to the habitat map into indicator(s) and associated spatial and temporal characteristics, and then to linking this information to mapped habitat types and associated spatial and temporal scales. With the appropriate level of knowledge about the physical and social environments, the methods described here can be replicated in other contexts. A 'degree of association' was calculated to provide a means of quantitatively assessing the strength of association between indicator(s) identified by stakeholders and habitat(s) delineated in the 2001 habitat map. The results of this technique provide a useful measure for determining whether satellite imagery can address coral reef management project objectives. This technique holds great potential for determining whether an investment in satellite imagery should be made in a coral reef management context.

10.1.4 Stage Four: Illustrating Remotely-Sensed Habitat Data and Cartographic Elements

A multitude of techniques is available for applying cartographic elements to a habitat map. However, the methods in this stage focus on integrating general structure, reference features, habitat type illustration, and map format. These categories were created using stakeholder feedback acquired during stage twoStage Two. The methods used here provide a clear and logical approach to integrating key cartographic elements. Therefore, in this stage, the management map is created, communicating habitat data using a language recognized and understood by each respective stakeholder group.

10.2 THE STRATEGY, MANAGEMENT MAP, AND CORAL REEF MANAGEMENT

It is important to note that throughout the three separate field seasons for this research several key themes emerged. Some themes are directly relevant to each of stages, and these themes were described in the concluding remarks of each respective chapter. Other themes, which relate to the overall functionality of the strategy are described below.

- Tradeoff between cost and scale. For example, the fishermen on Bunaken Island are familiar with the spatial location of seagrass and, in many places, how the concentration of seagrass has changed through time. The cost of having this same information illustrated in a temporal management map at a fine spatial scale may far exceed what fishermen can contribute and may far outweigh the real use of the information. A more cost effective approach may involve acquisition of free satellite imagery, with coarse spatial resolution, investigation of seagrass concentration change using multiple images, and development of a temporal management map that illustrates only those regions with a considerable gain or loss in seagrass. This method provides the same information as is provided by a change detection analysis with IKONOS satellite imagery, however, the cost of the imagery is removed from the overall budget. Generally, in the future, it will be important to assess whether the cost of acquiring fine spatial scale information outweighs the cost of the imagery.
- Communication between scientist and manager. Considerable effort was made by the researcher to learn the local language and local terminology used to describe the coral reef environment. Though, at times, simply knowing the terms was not enough to capture the context and essence of the message communicated by the manager. To enhance communication, shared experiences are critical. Workshops, field trips, and joint presentations create a collaborative environment, one in which both scientist and manager can ask questions of each other and work together to target the same objective/interest. Field trips, for example, are an excellent opportunity to expose the manager to the environment in which remotely-sensed field data are collected. Explanations on how the habitat data are collected and measured can be demonstrated, while in exchange the manager can ask questions

and provide stories or explanations for certain locations or the state of specific portions of the coral reef environment.

- Community-based research approaches. An important key theme in this research is that community-based research approaches warrant attention, investigation, and inclusion in the strategy. To both capture and utilize the local processes of environmental management, it is critical to know how community-based research is employed, what information is deemed relevant and useful, and how the information is used. Without knowledge of these factors, it is nearly impossible to integrate foreign information or processes. However, identifying this information is challenged by communication and physical barriers. In some instances, meetings are closed to the public, to foreign researchers or students, or to personnel that are not directly involved in a project. During such instances, effort must be made to attend, to provide some skill or product in exchange for attendence. Because, it is often during such meetings, that decisions are made and the process of how these decisions are made is critical information.

10.3 WEAKNESSES OF THE STRATEGY AND MANAGEMENT MAP

In each stage, the limitations to the methods are presented. To avoid repetition, this section will briefly highlight important areas that remain critical in the utilization of the strategy and the management maps. The primary limitation to the strategy is that it requires considerable time and effort by a coral reef remote sensing researcher: the habitat map is created by collecting field data in the coral reef environment, feedback from stakeholders is acquired by interviewing stakeholder respondents, and then using knowledge of the physical and social environments the feedback is deconstructed, translated, and illustrated. Each stage requires time and effort on behalf of both the researcher and the stakeholders, and most of the work cannot be delegated. Local personnel could collect field data and interview stakeholders, but it is important that the researcher him/herself understand the physical and social environments to better understand how to translate the indicator information and to how illustrate the cartographic elements. One of the greatest strengths of this research is that it requires the researcher to actively gather information by interacting with the physical and social environments; however, this is also a weakness, as it requires considerable time and effort. It also requires expert cross-cultural communication skills. Working with stakeholders within Indonesia required above average knowledge and use of local terminology and an understanding of how the words were intended. The researcher invested a considerable amount of time in learning the national language and, as well as local dialects in Manado and on Bunaken Island. The time invested in this task can be identified as a weakness of the strategy.

10.4 FUTURE RESEARCH OPPORTUNITIES

There are numerous future opportunities afforded by this research, and they include:

- Investigation of fishermen spatial perspectives of the physical environment and integration of these perspectives to the management map.
- Investigation of differences between local knowledge of the coral reef environment and habitat information as illustrated by a delineated satellite image.
- Integration of both stakeholder feedback and image and field data in an effective manner.

Within the last two years, Conservation International, the World Wildlife Fund for Nature, and The Nature Conservancy have collaborated on a research project to map the islands in Raja Ampat, Indonesia. The purpose of this project is to map the spatial location and extent of coral reefs, and then to work with local stakeholders on coral reef conservation. The strategy presented in this dissertation is an excellent contribution to such work. The strategy provides a step-by-step outline of how to integrated stakeholder feedback to create management maps that contain relevant information in a form and language that can be understood by the reader. Employing the strategy in this project is an excellent opportunity to assess how the strategy can be expedited and how it should be modified to a set of different social and cultural factors.

In a different environment, on the island of Unguja in Zanzibar, Africa, the World Bank has provided funds to map several coral reef environments. The purpose of this mapping project is to provide coral reef managers with an opportunity to develop maps that address local coral reef management concerns. Transforming the map into a form that is relevant and useful, however, is not part of the project. The strategy presented in this dissertation provides the necessary steps for transformation. In the next year, the researcher intends on employing this strategy in the Zanzibar context, and investigating how the strategy is modified to accommodate different physical, social, and cultural factors than those investigated on Bunaken Island.

10.5 CONCLUSION

In conclusion, this dissertation has outlined a series of stages that together provide a strategy to guide the use of remotely-sensed information in coral reef management for Bunaken Island, Indonesia. This research has contributed to advancing the application of remotely-sensed information in the management of coral reef resources by providing a set of objective and systematic methods that can be replicated in similar contexts. These contributions will assist in transforming future remotely-sensed habitat maps into management maps, in order to address specific coral reef management objectives. This will help move remote sensing of coral reefs away from its current focus on production of habitat maps with increasing detail and accuracy, and enable it to play a more active role as input to management of this precious environmental resource.

BIBLIOGRAPHY

Abbot, J. and 7 others. 1998. Participatory GIS: Opportunity or Oxymoroon? *PLA Notes.* 33: 27-33.

Agardy, T. 1997. *Marine protected areas and ocean conservation*. (Georgetown, Texas, R.G. Landes Company: Texas).

Ahmad, W. and D. Neil. 1994. An evaluation of Landsat Thematic Mapper ™ digital data for discrmination coral reef zonation: Heron Reef (GBR). *International Journal of Remote Sensing*. 15: 2583-2597.

Alcorn, J. 2001. *Borders, Rules and Governance: Mapping to Catalyse Changes in Policy and Management*. London, UK: International Insitute for Environment and Development.

Allee, R.J. and J. E. Johnson. 1999. Use of satellite imagery to estimate surface chlorophyll-a and Secchi disc depth of Bull Shoals Reservoir, Arkansas, USA. *International Journal of Remote Sensing*. 20: 1057-1072.

Andrefouet, S. and 15 others. 2003. Multi-site evaluation of IKONOS data for classification of tropical coral reef environments. *Remote Sensing of Environment*. 88 (1-2): 128-143.

Andrefouet, S., R. Berkelmans, L. Odriozola, T. Done, J. Oliver and F. Muller-Karger. 2002. Choosing the appropriate spatial resolution for monitoring coral bleaching events using remote sensing. *Coral Reefs.* 21: 147-154.

Andrefouet, S., F. Muller-Karger, E. Hochberg, C. Hu and K. Carder. 2001. Change detection in shallow coral reef environments using Landsat 7 ETM+ data. *Remote Sensing of Environment.* 79: 150-162.

Andrefouet, S. and C. Payri. 2001b. Scaling-up carbon and carbonate metabolism in coral reefs using in situ and remote sensing data. *Coral Reefs.* 19: 259-269.

Andrefouet, S. and M. Claereboudt. 2000. Objective class definitions using correclation of similarities between remotely sensed and environmental data. *International Journal of Remote Sensing.* 21(9): 1925-1930.

Aplin, P., P. Atkinson, and P. Curran. 1997. Fine spatial resolution satellite sensors for the next decade. *International Journal of Remote Sensing.* 18(18): 3873-3881.

Bartels, C. and A. Beurden. 1998. Using geographic and cartographic principles for environmental assessment and risk mapping. *Journal of Hazardous Materials.*: 115-124.

Birkeland, C. 1997. *Life and Death of Coral Reefs.* (Chapman and Hall: New York).

Brando, V. and S. Phinn. 2007. Coastal aquatic remote sensing applications for environmental monitoring and management. *Journal of Applied Remote Sensing.* Vol 1, 011599 (26 December 2007).

BNPMP. 1996. *Bunaken National Park Management Plan* (3 volumes). Bappenas, Ministry of Forestry, NRMP/USAID.

Bohnsack, T. and 9 others. 2002. A rationale for minimum 20-30% no-take protection. *Proc. 9th Int. Coral Reef Symposium. Bali, Indonesia.* Volume 2: 615-619.

Bray, J. and J. Curtis. 1957. An ordination of the upload forest communities of Southern Wisconsin. *Ecological Monostraphs.* 27: 325-349.

Bryant, D., L. Burke, J. McManus, and M. Spalding. 1998. *Reefs at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs.* (World Resources Institute: Washington).

Capolsini, P., S. Andrefouet, C. Rion and C. Payri. 2003. A comparison of Landsat ETM+, SPOT HRV, IKONOS, ASTER, and airborne MASTER data for coral reef habitat mapping in south pacific islands. *Canadian Journal of Remote Sensing.* 29 (2): 187-200.

Carver, S. 2001. Participation and Geographical Information: A Position Paper. *In: ESF-NSF Workshop on Access to Geographic Inforamtion and Participatory Approaches Using Geographic Information*, Spoleto, 6-8 December 1002.

Cesar, H., C. Lundin, S. Bettencourt, and J. Dixon. 1997. Indonesia coral reefs-an economic analysis of a precious but threatened resource. *Ambio.* 26: 345-350.

Chambers, R. 1997. *Whose Reality Counts? Putting the First Last.* London, UK: Intermediate Technology Publications.

Chambers, R. and I. Guijt. 1998. Pra - Five Years Later where Are We Now? *Forest, Trees, and People Newsletter.* 26/27.

Chambers, R., A. Pacey and L.A. Thrupp. 1989. *Famer First: Farmer Innovation and Agricultural Research.* London, UK: intermediate Technology Publications.

Chareonwongsak, K. 2001. *The Future of Society of Asia.* Munich: Center for Applied Policy Research (C.A.P).

Chauvaud, S., C. Bouchon, and R. Maniere. 1998. Remote sensing techniques adapted to high resolution mapping of tropical coastal marine ecosystems (coral reefs, seagrass beds and mangrove). *International Journal of Remote Sensing.* 19(18): 3625-3639.

Clark, C., P. Mumby, J. Chisholm, J. Jaubert, and S. Andrefouet. 2000. Spectral discrimination of coral mortality states following severe bleaching event. *International Journal of Remote Sensing.* 21(11): 2321-2327.

Clark, R., T. Fay, and C. Walker. 1987. Bathymetry calculations with Landsat 4 TM imagery under generalized ratio assumption. *Applied Optics.* 26(19): 4036-4038.

Cooke, A. 1994. The qoliqoli of Fiji - some preliminary research findings in realtion to mangement. Traditional marine tenure and sustainable management of marine resources in Asian and the Pacific. G. South, D. Goulet, S. Tuqiri and M. Church. Suva, Fiji, International Ocean Institute South Pacific**:** 179-182.

Cuevas-Jimenez, A. and P. Ardisson. 2002. Mapping of shallow coral reefs by colour aerial photography. *International Journal of Remote Sensing.* 23(18): 3697-3712.

Curran, P., E. Milton, P. Atkinson, and G. Foody. 1998. Remote Sensing: From Data to Understanding. Geocomputation: A Primer. P. Longley, S. Brooks, R. McDonnell and B. MacMillan. New York, John Wiley and Sons**:** 33-59.

David-Case, D.A. 1990 *The Community's Toolbox: The Idea, Methods and Tools for Participatory Assessment, Monitoring and Evaluation in Community Forestry.* Rome: Food and Agriculture Organization of the United Nations.

Dekker, A. G., Z. Zamurovic-Nenad, H. Hoogenboom, and S. Peters. 1996. Remote sensing, ecological water quality modeling and in situ measurements: a case study in shallow lakes. *Hydrological Sciences.* 41(4): 531-547.

DeVantier, L. and E. Turak. 2004. *Managing marine tourism in Bunaken National Park and adjacent waters, North Sulawesi, Indonesia.* Natural Resources Management (NRM): Jakarta.

Done, T. 1999. Coral Community adaptability to environmental change at the scales of regions, reefs, and reef zones. *American Zoologist.* 39: 66-79.

Eckert, M. 1977. On the nature of maps and map logic. Cartographica: The Nature of Cartographic Communication. L. Guelke. Toronto, Canada, University of Toronto Press. **19:** 1-7.

Edinger, E. and M. Risk. 2000. Reef classification by coral morphology predicts coral reef conservation value. *Biological Conservation.* 92: 1-13.

Edmunds, D. and E. Wollenberg. 2001. A strategic approach to multistakeholder negotiations. *Development and Change.* 32: 231-253.

Elliot, G., B. Mitchell, B. Wiltsire, and I. Manan. 2001. Community participation in marine protected management: Wakatobi National Park, Sulawesi, Indonesia. Coastal Management. 29: 295-316.

English, S., C. Wilkinson, and V. Baker. 1997. *Survey manual for tropical marine resources: 2nd Edition*. (Townsville: Australian Institute of Marine Science).

Erdmann, M., P. Merrill, M. Mongdon, I. Arsyad, Z. Harahap, R. Pangalila, R. Elverawati and P. Baworo. 2004. *Building effective co-management systems for decentralized protected areas management in Indonesia: Bunaken National Park Case Study.* Natural Resources Management (NRM): Jakarta.

Estep, L. and J. Holloway. 1992. Estimators of bottom reflectance spectra. International *Journal of Remote Sensing.* 13(2): 393-397.

Falkowski, P., P. Jokiel, and R. Kinzie III. 1998. Irradiance and corals: Chapter 5. <u>Ecosystems of the World: Coral Reefs</u>. Z. Dubinsky. Amsterdam, Elsevier. **25:** 89-104.

Fearnside, P. 1997. Transmigartion in Indonesia: Lesssons from its environmental and social impacts. *Environmental Management.* 21(4): 553-570.

Frederick W. and R. Worden. 1993. *Indonesia: A Country Study.* Washington D.C., Federal Research Division, Library of Congress.

Friedlander, A. and J. Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. *Journal of Experimental Marine Biology and Ecology.* 224 (1): 1-30.

Gash, J. and T. Arvidson. 2000. An assessment of Landsat 7/ETM+ coverage of coral reefs worldwide. In *Proceedings of the International Geosciences Symposium, Hawaii, USA*.

Goodman, J. and S. Ustin. 2007. Classification of benthic composition in a coral reef environment using spectral unmixing. Journal of Applied Remote Sensing. Vol 1, 011501. 26 December 2007.

Gower, J., R. Doerffer, and G. Borstad. 1999. Interpretation of the 685 nm peak in water-leaving radiance spectra in terms of fluorescence, absorption and scattering, and its observation by MERIS. *International Journal of Remote Sensing.* 20(9): 1771-1786.

Green, E., P. Mumby, and C. Clark. 2000. *Remote sensing handbook for tropical coastal management*. (France: Unesco Publishing).

Green, E., P. Mumby, A. Edwards, and C. Clark. 1996. A review of remote sensing for the assessment and management of tropical coastal resources. *Coastal Management.* 24: 1-40.

Gubbay, S. 1995. Marine protected areas - past, present and future. *Marine Protected Areas: Principals and Techniques for Management.* S. Gubbay (ed). (Chapman and Hall: London).

Harborne, A., P. Mumby, K. Zychaluk, J. Hedley, and P. Blackwell. 2006. Modeling the beta diversity of coral reefs. *Ecology.* 87 (11): 2871-2881.

Hardy, J. T., F. E. Hoge, J. Yungel, and R. Dodge. 1992. Remote detection of coral 'bleaching' using pulsed-laser fluorescence spectroscopy. *Remote Sensing of Environment. 88: 247-255.*

Harris, T. and W. Daniel. 2002. Implementing a Community-Integrated Gis: perspectiveds from South African Fieldwork. *Community Participation and Geographic Information Systems.* W. Craig, T. Harris and D. Weiner. London: New York, Taylor and Francis.

Harris, T. and D. Weiner. 1998. *Community-Integrated GIS for Land Reform in Mpumalanga Province, South Africa.* In: Empowerment, Marginalisation, Public Participation GIS Meeting, Santa Barbara, CA. National Center for Geographic Information and Analysis.

Hatcher, B. 1999. Varities of science for coral reef management. *Coral Reefs.* 18: 305-306.

Hedley, J. and P. Mumby. 2002. Biological and remote sensing perspectives of pigmentation in coral reef organisms. *Advances in Marine Biology.* 43: 279-317.

Hochberg, E. and M. Atkinson. 2000. Spectral discrimination of coral reef benthic communities. *Coral Reefs.* 19: 164-171.

Hochberg, E. and M. Atkinson. 2003. Capabilities of remote sensors to classify coral, algae, and sand as purse and mixed spectra. *Remote Sensing of Environment.* 85 (2): 174-189.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research.* 50 (8): 839-866.

Hof, T. 2002. Recruiting research that is useful to your MPA: Advice from experts. MPA News: International News and Analysis on Marine Protected Areas. Washington, DC. **3:** 1-2.

Holden, H. 1999. Samoa: Mapping the diversity. *Singapore Journal of Tropical Geography.* 20 (2): 214-216.

Holden, H. and E. LeDrew. 1998. The Scientific Issues Surrounding Remote Detection of Submerged Coral Ecosystems. *Progress in Physical Geography. 22: 190-221.*

Holden, H. and E. LeDrew. 1998b. Spectral Discrimination of Healthy and Non-Healthy Corals Based on Cluster Analysis, Principal Components Analysis, and Derivative Spectroscopy. *Remote Sensing of Environment. 65: 217-224.*

Jain, S. and J. Miller. 1977. Algebraic expression for the diffuse irradiance reflectivity of water from the two-flow model. *Applied Optics.* 16(1): 202-204.

Jennings, S. and N. Polunin. 1996. Fishing strategies, fishery development and socio-economics in traditionally management Fijian fishing grounds. *Fisheries Management and Ecology.* 3: 335-347.

Jordan, G. 2002. *GIS for Community Forestry User Groups in Nepal: Putting People Before the Technology. In:* Community Participation and Geographic Inforamtion Systems. W.J.Craig, T. Harris and D. Weiner. London: New Yrok, Traylor and Francis.

Johannes, R. 1998. Government-supported, village-based management of marine resources in Vanuatu. *Ocean and Coastal Management.* 40(2-3): 165-186.

Johannes, R. 1981. *Words of the Lagoon: Fishing and Marine Lore in the Palau District of Micronesia*. (Berkley, California: University of California Press).

Joyce, K. 2004. *A method for mapping live coral cover using remote sensing.* School of Geography, Planning and Architecture. Univeristy of Queensland, Brisbane. Doctoral Dissertation. 137 pp.

Joyce, K. and S. Phinn. 2002. Bi-directional reflectance of corals. *International Journal of Remote Sensing.* 23(2): 389-394.

Kelleher, G. 1999. *Guidelines for marine protected areas*. (IUCN: Switzerland).

Kirk, J. T. O. 1996. *Light and Photosynthesis in Aquatic Ecosystems.* (Cambridge University Press: Cambridge).

Klemas, V. 2001. Remote sensing of landscape-level coastal environmental indicators. *Enviromental Management.* 27(1): 47-57.

Kleypas, J., R. Buddemeier, and J. Gattuso. 2001. The future of coral reefs in an age of global change. *International Journal of Earth Sciences.* 90: 426-437.

Knight, D., E. LeDrew, and H. Holden*.* 1997. Mapping submerged corals in Fiji from remote sensing and in situ measurements: applications for integrated coastal management. *Ocean and Coastal Management.* 34(2): 153-170.

Knudby, A. and E. LeDrew. 2007. Measuring structural complexity on coral reefs. *AAUS Annual Symposium.* Miami, USA. March 9-10.

Kutser, T., I. Miller and D. Jupp. 2006. Mapping coral reef benthic substrates using hyperspectral space-borne images and spectral libraries. Estuarine Coastal and Shelf Science. 70 (3): 449-460.

Kyem, P. 2002. *Promoting Local Community Participation in Forest Mangement through a Ppgis Application in Southern Ghana. In* Community Participation and Geographic Information Systems. W. Craig, T. Harris and D. Winer. London: New York, Taylor and Franics.

LeDrew, E., H. Holden, M. Wulder, C. Derksen, and C. Newman. 2004. A spatial statistical operator applied to multidate satellite imagery for identification of coral reef stress. *Remote Sensing of Environment.* 91: 271-279

Lee, V. 2000. *Assessing ecotourism's abilities to generate community benefits: Bunaken National Park, Indonesia.* Department of Geography. University of Waterloo, Canada. 114 pp.

Lewis, J. B. 2002. Evidence from aerial photography of structural loss of coral reefs at Barbados, West Indies. *Coral Reefs. 21 (1):49-56.*

Liceaga-Correa, M. and J. Euan-Avila. 2002. Assessment of coral reef bathymetric mapping using visible Landsat Thematic Mapper data. *International Journal of Remote Sensing.* 23(1): 3-14.

Lillesand, T. and R. Kiefer. 1994. *Remote Sensing and Image Interpretation*. (New York: John Wiley and Sons, Inc.).

Lubin, D., W. Li, P. Dustan, C. Mazel, and K. Stamnes. 2001. Spectral signatures of coral reefs: Features from space. *Remote Sensing of Environment.* 75(1): 127-137.

Lunetta, R. and C. Elvidge. 1999. *Remote sensing and change detection.* (London: Taylor and Francis).

Lyzenga, D. R. 1978. Passive remote sensing techniques for mapping water depth and bottom features. *Applied Optics.* 17(3): 379-383.

Maeder, J. and 6 others. 2002. Classifying and mapping general coral-reef structure using IKONOS data. *Photogrammetric Engineering and Remote Sensing*. 68 (12): 1297-1305.

Maritorena, S., A. Morel, and B. Gentili. 1994. Diffuse reflectance of oceanic shallow waters: influence of water depth and bottom albedo. *Limnology and Oceanography.* 39(7): 1689-1703.

Mas, J.-F. 1999. Monitoring land-cover changes: a comparison of change detection techniques. *International Journal of Remote Sensing.* 20(1): 139-152.

Mazel, C. 1997. Coral fluorescence characteristics: excitation - emission spectra, fluorescence efficiencies, and contribution to apparent reflectance. *SPIE.* 2963: 240-245.

McConnell, S. 1998. *Connecting with the Unconnected: Proposing an Evaluation of the Impacts of the Internet of Unconnected Rural Stakeholders.* In: The First Mile of Connectivity. D. richardson and L. Paisley. Rome: Food and Agriculture Organization of the United Nations.

Mehta, A. 2000. *Bunaken National Park Natural History Guide*. NRM/EPIQ: Jarkarta.

Mishra, D., S. Narumalani, D. Rundquist and M. Lawson. 2005. High-resolution ocean color remote sensing of benthic habitats: A case study at the Roatan Island, Honuras. IEEE Transactions on Geoscience and Remote Sensing. 43 (7): 1592-1604.

Mobley, C. D. 1994. *Light and Water: Radiative Transfer in Natural Waters*. (Academic Press: San Diego).

Moetsabi, T. 1998. *Participatory Approaches for Promoting Rural Connectivity: An Exploration of Issues.* In: The First Mile of Connectivity. D. Richardson and L. Paisley. Rome: Food and Agriculture Organization of the United Nations.

Mumby, P.J., J.D. Hedley, J.R. Chisholm, C.D. Clark, H. Ripley, J. Jaubert. 2004. The cover of living and dead corals from airborne remote sensing. *Coral Reefs.* 23 (2): 171-183.

Mumby, P. and 7 others. Remote sensing of coral reefs and their physical environment. 2004. *Marine Pollution Bulletin.* 48: 219-228.

Mumby, P. and A. Edwards. 2002. Mapping marine environments with IKONOS imagery: enhanced spatial resolution can deliver greater thematic accuracy. *Remote Sensing of Environment.* 82: 248-257.

Mumby, P. 2001. Beta and habitat diversity in marine systems: a new approach to measurement scaling and interpretation. *Oecologia.* 128: 274-280.

Mumby, P. and A. Harborne. 1999. Development of a systematic classification scheme of marine habitats to facilitate regional management and mapping of Caribbean coral reefs. *Biological Conservation.* 88(2): 155-163.

Mumby, P. J., E. P. Green, A. Edwards, and C. Clark. 1997. Coral reef habitat mapping: how much detail can remote sensing provide. *Marine Biology.* 130: 193-202.

Neil, D. T., S. R. Phinn, and W. Ahmad. 2000. Reef zonation and cover mapping with Landsat Thematic Mapper data: intra- and inter-reef patterns in the Southern Great Barrier Reef region. *In Proceedings of the International Geosciences and Remote Sensing Symposium.*

Newman. C. and E. LeDrew. 2007. Assessing the effect of management zonation on live coral cover using mulit-date IKONOS satellite imagery. *Journal of Applied Remote Sensing.* Vol 1, 011501. 26 December 2007.

Newman, C. and E. LeDrew. 2005. Towards Community- and Scientific-Based Information Integration in Marine Resource Management in Indonesia: Bunaken National Park Case Study. *Environments: A Journal of Interdisciplinary Studies.* 33(1): 4-24.

Newman, C. and E. LeDrew 2002. Assessing the Uncertainty of Radiometric Properties in Coral Reef Environments. *In Proceedings of the International Geosciences and Remote Sensing Symposium, Toronto, Canada.*

Newman, C. 2001. *Testing the Assumptions Surrounding Information Extraction from Remotely Sensed Imagery of Coral Reef Environments.* Department of Geography. Waterloo, University of Waterloo**:** 132 pp.

Nickerson, D. and S. Olsen. 2003. *Collaborative Leaning Initiatves in Integrated Coastal Management*. Coastal Management Report#2239. University of Rhode Island, Coastal REsources Center. Narragansett, Rhode Island USA. 39 pp.

Norrish, P. 1998. *Radio and Video for Development:* In: The First Mile of Connectivity. D. Richardson and L. Paisley. Rome: Food and Agriculture Organization of the United Nations.

Ohde, T. and H. Siegel. 2001. Correction of bottom influence in ocean colour satellite images of shallow water areas of the Baltic Sea. *International Journal of Remote Sensing.* 22(2 & 3): 297-313.

Palandro, D., S. Andrefouet, P. Dustan, F. Muller-Karger. 2002. Comparison of remote sensing change detection results from varying spatial resolution for a coral reef environment in the Florida Keys. *Seventh International Conference on Remote Sensing for Marine and Coastal Environments, Miami, Florida*.

Pet-Soede, C., J. Cesar, and J. Pet. 1999. An economic analysis of blast fishing on Indonesian coral reefs. *Environmental Conservation.* 26(2): 83-93.

Philpot, W. D. 1989. Bathymetric mapping with passive multispectral imagery. *Applied Optics*. 28(8): 1569-1578.

Phinn, S. R., D. T. Neil, K. Joyce, and W. Ahmad. 2000. Coral reefs: a multi-scale approach to monitoring their composition and dynamics. *In Proceedings of the International Geosciences Remote Sensing Symposium.*

Phinn, S., C. Menges, G. Hill and M. Standford. 2000. Optimising remotely sensed solutions for monitoring, modelling and managing coastal environments. *Remote Sensing of Environment.* 73: 117-132.

Phinn, S. 1998. A framework for selecting appropriate remotely sensed data dimensions for environmental monitoring and management. *International Journal of Remote Sensing.* 19(17): 3457-3463.

PHKA. 2002. *Technical guidance on zonation of Indonesia's Marine National Park System.* In: Pedoman Penataan Zona Taman Nasional Perairan Laut. Jakarta. 42 pp.

Populus, J., W. Hastuti, J. Martin, O. Guelorget, B. Sumartono, and A. Wibowo. 1995. Remote sensing as a tool for diagnosis of water quality in Indonesian seas. *Ocean and Coastal Management.* 27(3): 197-215.

Porter, J. and J. Tougas. 2001. Reef ecosystems: threats to their biodiversity. *Encyclopedia of Biodiversity.* 5: 73-95.

Pretty, J., I. Guijt, J. Thompson and I. Scoones. 1995. *Participatory Learning and Action: A Trainders Guide.* London: IIED.

Purkis, S., S. Myint, B. Riegl. 2006. Enhanced detection of the coral Acropora cervicornis from satellite imagery using a textural operator. *Remote Sensing of Environment.* 101 (1): 82-94.

Purkis, S., J. kenter, E. Oikonomou and I. Robinson. 2002. High resolution ground verification, cluster analysis and optical model of reef substrate coverage on Landsat TM imagery (Red Sea, Egypt). *International Journal of Remote Sensing.* 23, 1677-1688.

Richardson, D. 1997. *The Internet and Rural and Agricultural Development.* Rome, Food and Agriculture Organization of the United Nations.

Ricklefs, M. 2001. *A History of Modern Indonesia since C. 1200.* Stanford, CA: Standford University Press.

Riegl, B. and S. Purkis. 2005. Detection of shallow subtidal corals from IKONOS satellite and QTC View (50, 200 kHz) single-beam sonar data (Arabian Gulf; Dubai, UAE). *Remote Sensing of Environment.* 95 (1): 96-114.

Riegl, B. and W. Piller. 2000. Mapping of bethic habitats in northern Safaga Bay (Red Sea, Egypt): A tool for proactive management. *Aquatic Conservation: Marine and Freshwater Ecosystems.* 10: 127-140.

Risk, M. 1999. Paradise lost: how marine science failed the world's coral reefs. *Marine and Freshwater Research.* 50 (8): 831-837.

Risk, M. 1972. fish diversity on coral reef in the Virgin Islands. *Atoll Research Bulletin.* 153: 1-6.

Robinson, I. S. 1985. *Satellite Oceanography*. (John Wiley and Sons: New York).

Salichtchev, K. 1977. *Some reflections on the subject and method of cartography after the sixth international cartographic conference.* Cartographica: The Nature of Cartographic Communication. Edited by L. Guelke. (Toronto: University of Toronto Press).

Scubazoo, Team. 2007. *Reef.* London, UK: Dorling Kindersley.

Sheppard, C., K. Matheson, J. Bythell, P. Murphy, C. Myers, and B. Blake. 1995. Habitat mapping in the Caribbean for management and conservation: use and assessment of aerial photography. *Aquatic Conservation: Marine and Freshwater Ecosystems.* 5: 277-298.

Siegal, H., M. Gerth, T. Neumann, and R. Doerffer. 1999. Case studies on phytoplankton blooms in coastal and open waters of the Baltic Sea using Coastal Zone Color Scanner data. *International Journal of Remote Sensing.* 20(7): 1249-1264.

Spitzer, D. and R. W. J. Dirks. 1987. Bottom influence on the reflectance of the sea. *International Journal of Remote Sensing.* 8(3): 279-290.

Stumpf, R. and 9 others. 2000. SeaWiFS ocean color data for US Southeast coastal waters. In *Proceedings of the Sixth International Conference on Remote Sensing for Marine and Coastal Environments, Charleston, South Carolina.*

Souter, D. and O. Linden. 2000. The health and future of coral reef systems. *Ocean and Coastal Management.* 43: 657-688.

Specter, C. and D. Gayle. 1990. Managing technology transfer for coastal zone development: Caribbean experts identify major issues. *International Journal of Remote Sensing.* 11(10): 1729-1740.

Suryadinata, L. 2002. *Elections and Politics in Indonesia.* Singapore: Institute of South EAst Asian Studies.

Tassan, S. 1996. Modified Lyzenga's method for macroalgae detection in water with non-uniform composition. *International Journal of Remote Sensing.* 17(8): 1601-1607.

Thamrongnawasawat, T. and D. Hopley. 1994. Digitised aerial photography applied to small area reef management. *Recent Advances in Marine Science and Technology.* 94: 389-394.

Tsai, F. and W. Philpot. 1998. Derivative Analysis of Hyperspectral Data. *Remote Sensing of Environment.* 66: 41-51.

Turnerk, J. and R. Klaus. 2005. Coral reefs of the Mascarenes, Western Indian Ocean. *Philosophical Transactions of The Royal Society A*. 363: 229-250.

Usher, G. and R. Merrill. 2000. *Bunaken National Park: Participatory Management in Zoning. In:* Salm R. and J. Clark [eds]. Marine and Coastal Protected Areas: A guide for planners and managers. 3rd Edition. IUCN. Pp. 247-252.

Veitayaki, J. 1998. Traditional and Community-Based Marine Resources Management System in Fiji: An Evolving Integrated Process. *Coastal Management.* 26: 47-60.

Veron, J. 2000. Corals of the World. Townsville: AIMS. Volume 1.
Wasserman, A. 1975. *Biology*. (London: Addison-Wesley).

Websters Universal Dictionary and Thesauraus. 1993. Montreal, Tormont**:** 960 pp.

Wells, S., N. Burgess and A. Ngusara. 2007. Towards the 2012 marine protected area targest in Eastern Africa. *Ocean and Coastal Management.* 50 (1-2): 67-83.

Wilkinson, C. 2000. *Status of Coral Reefs of the World: 2000*. (Australian Institute of Marine Science: Queensland).

Wismer, S., T. Babcock and B. Mitchell. 2005. From Sky to Sea: Capacity-Building for Enviornmental Management in Indonesia). Waterloo: Geography Publication Series. 678 pp.
World Bank. 1994. Indonesia: Environment and Development. *A World Bank Country Study.*